FEASIBILITY STUDY

Lake Havasu Avenue and Holly Avenue

Water Quality Assurance Revolving Fund Site

Lake Havasu City, Arizona

Prepared for

Arizona Department of Environmental Quality
1110 West Washington Street
Phoenix, Arizona 85007

Prepared by

Geosyntec Consultants, Inc.
11811 N. Tatum Blvd., Suite P-186
Phoenix, Arizona 85028

Project Number: SP0164

September 2022

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ACRONYMS AND ABBREVIATIONS

1,1-DCE	1,1-dichloroethene
1,2-DCA	1,2-dichloroethane
µg/L	Micrograms Per Liter
$\mu g/m^3$	Micrograms Per Cubic Meter
A.A.C.	Arizona Administrative Code
ADEQ	Arizona Department of Environmental Quality
ADWR	Arizona Department of Water Resources
amsl	Above Mean Sea Level
A.R.S.	Arizona Revised Statutes
AWQS	Aquifer Water Quality Standard
CAB	Community Advisory Board
CaS_x	Calcium Polysulfide
COCs	Contaminants of Concern
Cr(III)	Trivalent Chromium
Cr(VI)	Hexavalent Chromium
DEUR	Declaration of Environmental Use Restriction
EPA	United States Environmental Protection Agency
EVO	Emulsified Vegetable Oil
FS	Feasibility Study
ft bgs	Feet Below Ground Surface
GETS	Groundwater Extraction and Treatment System
GPL	Groundwater Protection Level
gpm	Gallons Per Minute
HFCS	High Fructose Corn Syrup
ISB	In Situ Bioremediation
ISCR	In Situ Chemical Reduction
LGAC	Liquid-Phase Granular Activated Carbon
LHC	Lake Havasu City
LWUS	Land and Water Use Study
MEK	Methyl Ethyl Ketone
mg/kg	Milligrams Per Kilogram
MNA	Monitored Natural Attenuation
O&M	Operations and Maintenance
PCE	Tetrachloroethene
PI	Preliminary Investigation
PVC	Polyvinyl Chloride
RI	Remedial Investigation
ROs	Remedial Objectives
SRL	Soil Remediation Level

SVE	Soil Vapor Extraction
SVSL	Soil Vapor Screening Level
TCA	1,1,1-trichloroethane
TCE	Trichloroethene
USEPA	United States Environmental Protection Agency
VOCs	Volatile Organic Compounds
VRP	Voluntary Remediation Program
WQARF	Water Quality Assurance Revolving Fund
ZVI	Zero Valent Iron

1. INTRODUCTION

1.1 Purpose and Scope of the Feasibility Study Report

Geosyntec Consultants, Inc. (Geosyntec) has prepared this Feasibility Study (FS) Report for the Lake Havasu Avenue and Holly Avenue Water Quality Assurance Revolving Fund (WQARF) Site (the Site) located in Lake Havasu City, Arizona (Figures 1 and 2). This FS was prepared for the Arizona Department of Environmental Quality (ADEQ) in accordance with Arizona Administrative Code (A.A.C.) Title 18, Environmental Quality, Chapter 16, Department of Environmental Quality WQARF Program, Article 4, Remedy Selection (R18-16), and is based on the data and findings of previous investigations, including the Remedial Investigation (RI) Report (Geosyntec and ADEQ, 2020).

The objectives of this FS are as follows:

1. Identify remedial alternatives that will achieve the Remedial Objectives (ROs) as outlined in the Final Remedial Objectives Report included in the RI Report (Geosyntec and ADEQ, 2020); and
2. Evaluate the identified remedies, recommend alternatives, and comply with the requirements of Arizona Revised Statutes (A.R.S.) §49-282.06.

Based on the objectives stated above, the FS presents a recommended remedy, which:

1. Assures the protection of public health, welfare, and the environment;
2. To the extent practicable, provides for the control, management, or cleanup of hazardous substances to allow for the maximum beneficial use of waters of the state;
3. Is reasonable, necessary, cost effective, and technically feasible; and
4. Addresses groundwater wells used for municipal, domestic, industrial, irrigation or agricultural purposes that could produce water that would not be fit for its current or reasonably foreseeable end use without treatment.

1.2 Report Organization

The remainder of this FS report is organized as follows:

- Section 2 "Site Background" - Presents a Site description, a summary of the Site history, including geologic/hydrogeological setting, the nature and extent of contamination, and a risk evaluation;
- Section 3: "Feasibility Study Scoping" presents the regulatory requirements of pertinent statutes and rules, delineates the remediation areas, and presents the ROs identified by ADEQ;
- Section 4: "Identification and Screening of Remediation Technologies" presents an evaluation and screening of various remedial technologies related to contamination in soil

and groundwater, and lists the technologies that have been retained for inclusion into the reference and alternative remedies;

- Section 5: “Development of Reference Remedy and Alternative Remedies” presents the evaluation process and selection of a Reference Remedy, a More Aggressive Remedy, and a Less Aggressive Remedy;
- Section 6: “Comparison of Remedies” presents a summary of the three remedial alternatives compared to each other based on practicability, risk, cost, and benefit, and includes a discussion of uncertainties associated with each remedy;
- Section 7: “Recommended Remedy” presents the recommended remedy and discusses how the remedy will meet the requirements of A.R.S. §49-282.06 and A.A.C. R18-16-407(I);
- Section 8: “Community Involvement” discusses public participation; and
- Section 9: “References” provides a list of references cited in this report

2. SITE BACKGROUND

This section presents a summary of the Site background, physiographic setting, the nature and extent of contamination, and a risk evaluation. Additional background details are presented in the RI Report.

2.1 Site Description

The Site, located in Lake Havasu City (LHC), is situated approximately one mile east of Lake Havasu (Figure 2). The Site is generally bounded to the north by Centers Avenue, to the south by Holly Avenue, to the east by San Juan Drive, and to the west by Aviation Drive. The Site is in an urban setting that includes a mixture of commercial businesses, light industrial businesses, warehouses, and residential neighborhoods.

The Site boundaries are defined by the known limits of soil contamination above Soil Remediation Levels (SRLs) and the combined groundwater plumes for Site-related contaminants of concern (COCs) above Aquifer Water Quality Standards (AWQS). Site-related COCs include hexavalent chromium ([Cr(VI)] in soils), chromium (in groundwater), nitrate, and chlorinated volatile organic compounds (VOCs) including tetrachloroethene (PCE) and trichloroethene (TCE). While 1,2-dichloroethane (1,2-DCA), 1,1-dichloroethene (1,1-DCE), and nitrite have also been detected over AWQS periodically at the Site, they are not considered COCs at this time as concentrations exceeding AWQS have been very limited both spatially and over time, and any remedial action selected at the Site for PCE, TCE, and nitrate will address any remnants of these contaminants as well. The current Site boundaries are depicted on the Site Plan (Figure 2).

2.2 Site History and Former Facility Operations

The following is a summary of Site history based on information from the RI Report.

In approximately 1960, a manufacturing facility for the assembly of sewing machine motors and gyrocopters was built on a property at 900 N Lake Havasu Avenue. In 1972, the McCulloch Corporation (McCulloch) purchased the property, and subsequently used the property for manufacturing chain saws and gardening equipment. Manufacturing activities included dye casting, degreasing, maintenance operations, machining, metal finishing, and chrome plating. Known chemicals that were used at the facility included metals (chromium), acids and bases, cyanide compounds, oxidizers, adhesives, phenolic surfactants, and a variety of solvents. Operations ceased in 1998 and McCulloch vacated the property due to its bankruptcy in 1999. Figure 3 presents the historical layout of the McCulloch Facility.

According to a Resource Conservation and Recovery Act Preliminary Assessment, the facility's waste streams included chromium, 1,1,1-trichloroethane (TCA), waste paint filters and bags, waste paint, polyvinyl chloride (PVC) liners, methyl ethyl ketone (MEK), cyanide, trichlorotrifluoroethane (Freon 113), baghouse dust, wastewater, and waste oil. PCE and TCE were used in the degreasing process, and nitric acid was used in the plating process. Chromium waste from plating activities was treated in sludge sumps in the northwest portion of the former McCulloch facility prior to 1984. Several chemical storage areas were also located in this general area. After 1984, chromium waste was treated via dewatering in a filter-press to form a cake. The cake was stored in roll-off bins and shipped off the facility; whereas the water extracted in the process was treated and discharged to the Kiowa Ponds (discussed further below). Waste TCA, paint, rags, filters, PVC liners, and MEK were stored in 55-gallon drums and shipped off the facility for disposal.

The Lake Havasu Sanitary District constructed two infiltration ponds (the Kiowa Ponds) to the west of the former McCulloch facility (Figure 3). The ponds became the property of LHC when it was incorporated in 1978 and the district was dissolved. The ponds were a two-cell, unlined percolation and evaporation lagoon system for wastewater disposal from the former McCulloch's manufacturing activities. According to the Waste Storage and Handling Closure Plan completed on behalf of the former McCulloch facility, industrial sewage was treated on the facility property through a three-stage clarifier, and the resulting industrial wastewater was discharged at the Kiowa Ponds. Approximately 230,000 gallons of wastewater a day were reported to have been discharged to the ponds. Details on the composition of these discharges are presented in the RI Report.

When the Kiowa Ponds reached capacity, wastewater was transferred to the Kiowa Wash located directly north of the ponds. Treated effluent from the Site overflowed via a discharge pipe from the ponds into the Kiowa Wash (Figure 3). LHC also used a pump-and-spray irrigation system to transfer water to the wash. LHC could also bypass the ponds and discharge the water directly to the wash, covered by NPDES permit AZ0021819. In 1995, the former McCulloch facility was connected to the LHC sewer system, and the ponds ceased receiving effluent from the former McCulloch facility. The areas of the former ponds were excavated by LHC, and clean backfill was imported to the property for cover (Geosyntec and ADEQ, 2020).

LHC entered ADEQ's Voluntary Remediation Program (VRP) to address possible residual soil contamination in the former Kiowa Ponds area. After additional investigations, no Site COCs were identified in soil or the vadose zone in the former ponds area above SRLs, and the VRP site was given clean closure (ADEQ, 2019)

Currently, the 900 N Lake Havasu Avenue property is leased for offices and temporary warehousing of consumer products, excluding the former plating shop area, which is vacant. The former Kiowa Ponds property is currently vacant land.

As described in the RI Report, from at least the early 1980's to 2018, the Site has been the subject of numerous investigations focusing on groundwater, soil, and soil gas contamination. The preliminary investigation (PI) stage of the WQARF investigation was initiated in 2015. The Site was placed on the WQARF Registry on December 4, 2017, with an Eligibility and Evaluation Score of 50 out of 120 (ADEQ, 2018). In February 2018, ADEQ sent out notices in accordance with A.R.S. §49-287.03 initiating the RI for the Site.

2.3 Conceptual Site Model Summary

The following summarizes the Site geology, hydrogeology and extent of contamination presented in the RI Report.

2.3.1 Site Geology

The Site is underlain by deposits of unconsolidated recent alluvium and older basin-fill deposits of sand, gravel, cobbles, and soil, with minor clay and local caliche horizons. Beneath the alluvium and basin-fill deposits is the older, more consolidated Bouse Formation, which is encountered at approximately 300 to 1,110 feet above mean sea level (ft amsl) in the Chemehuevi Valley and comprised chiefly of fine-grained marine and brackish water limestones, along with siltstones and claystones.

Numerous dry washes cut through the river terraces to Lake Havasu, including the Kiowa Wash located immediately north of the former McCulloch property. The layers of gravels and cobbles, interspersed with discontinuous lenses of fine-grained sedimentary sand and silt, tend to dip to the west.

Based on lithological logs of continuous-core borings from the Site, the subsurface is comprised of discontinuous and heterogeneous interbedded sediments typical of alluvial fan deposits. In general, the lithology encountered during drilling includes sands (including well-graded and poorly graded sands, silty sands, clayey sands, and gravelly sands), gravels (mostly fine-grained gravels with sand), cobbles, and silts (including silt, silts with gravel, silt with sand, and sandy silts). Discontinuous lean clays were also encountered in some borings, although the presence of laterally continuous clay layers appears to be limited across the Site.

2.3.2 Site Hydrogeology

The Site is located in the Lake Havasu - Chemehuevi Valley area, which has been designated by the Arizona Department of Water Resources (ADWR) to be within the Lake Havasu Basin of the Upper Colorado River Planning Area. Lake Havasu is a large reservoir formed on the Colorado River by Parker Dam; the lake is approximately one mile to the west of the Site. Groundwater occurs in the interbedded gravel and sand basin-fill sediments underlying the Site. According to ADWR, most of the wells in the basin penetrate the upper 100 to 200 ft of the basin-fill, where groundwater is hydraulically connected to the Colorado River. According to ADWR, regional groundwater in the Lake Havasu Basin flows from north to south.

Based on the September 2020 depth-to-water measurements, groundwater elevations at the Site ranged from approximately 454 ft amsl in LHH-05 (in the western portion of the Site) to approximately 471 ft amsl in MW-2 (in the eastern portion of the Site; Figure 4).

LHC production wells (LHC-10, LHC-11, LHC-12, LHC-13, LHC-14, LHC-15, and LHC-18) are located approximately 0.7 mile west of the former McCulloch facility (Figure 2), in what is referred to by LHC as the north wellfield. Since 2004, production from the north wellfield has discontinued, replaced by LHC wells located approximately 2.5 miles south of the Site; however, the LHC production wells located west of the Site are occasionally operated to maintain pump performance.

According to the RI Report, the combination of abnormally wet months in 2004-2005, and LHC discontinuing pumping from the north wellfield has likely contributed to an overall increase in groundwater elevations at the Site; groundwater elevations in 2020 were approximately 25 ft higher than groundwater elevations measured prior to 2004.

During 2020, the general direction of groundwater flow was west-southwest with a horizontal hydraulic gradient of approximately 0.004 feet per foot (Figure 4).

2.3.3 Extent of Contamination

Based upon the data collected during the RI, the 2020 groundwater monitoring event, and review of findings from previous investigations, the following sections summarize the extent of soil, soil gas, and groundwater contamination at the Site.

2.3.3.1 Extent of Soil Contamination

As indicated in the RI Report, Cr(VI) exceeding SRLs were detected in soils in the area near the former plating shop at the former McCulloch facility (Figure 3). Evaluation of 1992 and 1996 data shows that chromium was present from the soil surface to groundwater (Figure 5). Soil borings drilled for the RI located in the same area in 2018 confirmed that the magnitude of the total chromium detected was comparable to Cr(VI), and that both constituents remained present in soils in this area (Figure 6).

2.3.3.2 Extent of Soil Gas Contamination

The results of the RI indicate that PCE, TCE, and other VOCs were present in soil gas samples collected in the vicinity of the former plating shop and the former Main Plant Warehouse and Assembly areas at the former McCulloch facility (Figures 7 and 8). PCE and TCE were detected above soil vapor screening levels (SVSLs) to a depth of 115-feet below ground surface (ft bgs). While the RI found that multiple VOCs were detected above the SVSLs, none of the compounds were detected above SRLs or groundwater protection levels (GPLs). Soil gas samples collected near to the former Kiowa Ponds area did not indicate PCE or TCE contamination.

2.3.3.3 Extent of Groundwater Contamination

As documented in the RI Report, chromium, VOCs, and nitrate have been detected in groundwater at concentrations that exceed their respective AWQS. Based on Site investigations, the RI and groundwater monitoring events, the source area for most of these COCs is in the vicinity of the former McCulloch facility. Further details on the extent of groundwater contamination by these COCs is presented below.

<u>Chromium</u>

In 2020, the groundwater chromium plume extended approximately 3,000 ft, from approximately MW-20 to beyond well LHH-02 (Figure 9), in a plume approximately 600 ft wide. As described in the RI Report, the plume dives as it moves downgradient from east to west; in the east it extends from the top of the water table to approximately 150 ft below the water table. In the vicinity of MW-8/KPMW-1, the plume is only detected in the lower part of the screen of these wells, indicating that the top of the plume dives to approximately 30 to 50 ft below the top of the water table. In the area of the former Kiowa Ponds, the chromium plume was not detected in the screen of KPMW-3 but was present in I-3A and LHH-02, indicating the plume extended from greater than 50 ft to approximately 200 ft below the water table (Figures 10, 11, 12, and 13).

<u>VOCs</u>

In 2020, the groundwater TCE plume extended approximately 1,900 ft west of the source area near the former plating shop to monitoring well LHH-02 (Figure 14). The RI Report found that the depth of the TCE plume approximates that of the chromium plume, also diving as it moves east to west (Figure 15).

In 2020, the groundwater PCE plume was limited to the area near the former plating shop and the former Main Plant Warehouse and Assembly areas, and extending to approximately 100 feet downgradient (Figure 16). The RI found that the depth of this plume appears to be limited to the top 65 feet of the water table in the area of the Main Plant Warehouse.

The RI reported that 1,2-DCA above AWQS was limited to the area around the LHH-07 and I3-B wells, and 1,1-DCE was only detected above AWQS in MW-9; similar findings were also found in 2020 groundwater sampling. Benzene was not detected above AWQS in the 2019 or 2020 sampling events.

Nitrate

As indicated in the RI Report, the extent of nitrate in the aquifer is influenced by background nitrate concentrations in the area groundwater, and based on nitrogen isotope analysis, nitrate may be from a sewage or septic source, possibly indicating potential ongoing issues with sewer lines or unknown septic tanks in the region upgradient of MW-1. Upgradient wells varied from 11,000 µg/L to 29,000 µg/L in the fall 2019 sampling event. Levels over these background numbers (ranging from 48,000 to 210,000 µg/L) extended approximately 3,500 feet, from MW-1 to slightly beyond LHH-03 (Figure 17). The RI Report indicated that this plume also dives as it moves east to west, as indicated by the results in the I-3, I-4, and I-5 wells (Figure 18).

2.4 Risk Evaluation Summary

An evaluation of current land and water use was performed for the Site. Land use is limited to commercial/industrial uses in the areas where the results of the RI indicate that concentrations of impacts to soil and soil gas exceed standards and screening levels; therefore, a commercial/industrial use scenario is assumed for risk evaluation. Because land use includes commercial and industrial occupancy, potential receptors therefore include commercial/industrial workers. Impacted media at the Site include groundwater, soil, and soil gas.

The identification of potentially complete exposure pathways is based on four components, which include:

1. A source and mechanism of release;
2. Retention or transport media (pathway);
3. An exposure point (i.e., a setting where contact with impacted media occurs); and
4. A route of exposure (e.g., ingestion, dermal, inhalation).

2.4.1 Soil Pathway

Concentrations of Cr(VI) above SRLs occur at various shallow and deep depths below barriers (i.e., concrete slabs, paved or asphalted surfaces), so they are inaccessible to direct contact by humans unless there is an excavation beneath the barrier. The current land use is commercial and industrial in the areas where the results of the RI indicate that concentrations in soil exceed SRLs.

For a continued future industrial/commercial scenario, the soil direct contact pathway would remain incomplete while these areas remain paved. If these properties are redeveloped, this exposure pathway would require re-evaluation by additional sampling to determine if chromium in soil exceeds screening levels.

The RI determined that transport mechanisms for a soil pathway include excavation and fugitive dust. Dermal and incidental ingestion exposure route (applicable to construction workers in contact with trench spoils) presents a future potentially complete exposure pathway.

2.4.2 Soil Gas Pathway

The RI Report states that transport of vapor-phase constituents present in the soil gas to indoor air could result in exposure to human health risk via inhalation. The transport mechanism for a vapor pathway is volatilization from residual VOCs in the vadose zone followed by subsequent vapor intrusion. The secondary impacted media are indoor and outdoor air.

The RI Report states that several VOCs were detected in soil gas, including PCE and TCE at a maximum of 130,000 micrograms per cubic meter ($\mu g/m^3$) and 11,000 $\mu g/m^3$, respectively. The areas where the results of the RI indicate impacts to soil gas are restricted to commercial and industrial. The soil gas values exceed SVSLs for non-residential use; therefore, the RI Report indicates that the inhalation exposure route could affect certain receptors and is considered a potentially complete exposure pathway.

Due to the depth of the groundwater (ranging from approximately 50- to 125-ft bgs), the relatively low concentrations of VOCs in groundwater, and limited extent of the VOC plumes away from the potential source area, groundwater is not expected to be a significant source of VOCs in soil gas at this time, and the RI report stated that this pathway may not be significant.

2.4.3 Groundwater Pathway

As described in the RI Report, Site groundwater investigations have determined that several COCs impact groundwater at levels above their respective AWQS, principally including chromium, PCE, TCE, and nitrate. The RI Report states that direct ingestion is a potential exposure route for potable use chromium- and nitrate- impacted groundwater, and that possible exposure routes for VOC-impacted groundwater used for potable water include direct ingestion, inhalation, or dermal contact.

At this time, these groundwater exposure pathways are incomplete, as the LHC production wells located west of the Site in the north wellfield currently operate only occasionally for pump maintenance. Furthermore, based on groundwater monitoring results, the concentration of Site COCs do not currently exceed their respective AWQS in the immediate vicinity of the LHC production wells. If production wells in the north wellfield are utilized in the future for water supply, this exposure pathway would require re-evaluation.

2.4.4 Surface Water Pathway

According to the RI Report, there are no known points of natural discharge of groundwater to surface water within one mile of the Site, and the Site COCs are not known to have reached Lake Havasu. Therefore, this pathway is currently considered incomplete. If in the future, Site COCs exceeding the AWQSs are detected close to the lake, then this pathway would require re-evaluation.

3. FEASIBILITY STUDY SCOPING

The following presents the regulatory requirements of pertinent statutes and rules, the delineation of the remediation areas, and the ROs identified by ADEQ.

3.1 Regulatory Requirements

In accordance with A.R.S. §49-282.06, the following factors must be considered for selecting remedial actions:

- Population, environmental, and welfare concerns at risk;
- Routes of exposure;
- Amount, concentration, hazardous properties, environmental fate, such as the ability to bio-accumulate, persistence and probability of reaching the waters of the state, and the form of the substance present;
- Physical factors affecting environmental exposure, such as hydrogeology, climate, and the extent of previous and expected migration;
- The extent to which the amount of water available for beneficial use will be preserved by a particular type of remedial action;
- The technical practicability and cost-effectiveness of alternative remedial actions applicable to a site; and
- The availability of other appropriate federal or state remedial action and enforcement mechanisms, including, to the extent consistent with this article, funding sources established under the Comprehensive Environmental Response, Compensation, and Liability Act, to respond to the release.

The Remedy Selection Rule, A.A.C. R18-16-407, states that an FS is a process by which to identify a reference remedy and alternative remedies that appear to be capable of achieving ROs and to evaluate the remedies based on the comparison criteria to select an approach that complies with A.R.S. §49-282.06.

3.2 Delineation of Remediation Areas

The following subsections discuss the delineation of impacts to soil, the vadose zone and groundwater at the Site.

3.2.1 Soil

Total chromium exceeds minimum the GPL of 590 milligrams per kilogram (mg/kg) and hexavalent chromium exceeds the non-residential SRL of 65 mg/kg in soils in the vicinity of the former plating area at the former McCulloch facility. The highest total chromium concentration in soil was 6,200 mg/kg. The highest Cr(VI) concentration in soil was 1,200 mg/kg in a sample collected at 130-ft bgs. The SRL for Cr(VI) was exceeded at all sampled depths except for select samples collected at 3-ft and 5-ft bgs depths in some boreholes in the vicinity of the former plating area (Figure 6). Soil concentrations of Cr(VI) exceeded the SRL from near ground surface to at least 170-ft bgs.

3.2.2 Vadose Zone

Eight VOCs were detected at concentrations that exceeded their respective SVSLs in the vadose zone near to the former Main Plant Warehouse and plating area at the former McCulloch facility. The SVSLs were derived for non-residential properties based on the USEPA composite worker air Regional Screening Levels (USEPA, 2018) and an attenuation factor of 0.03. The maximum concentration of the eight VOCs detected in exceedance of their respective SVSLs are as follows:

- PCE at 130,000 $\mu g/m^3$ (SVSL of 1,567 $\mu g/m^3$);
- TCE at 11,000 $\mu g/m^3$ (SVSL of 100 $\mu g/m^3$);
- 1,1-DCA at 1,800 $\mu g/m^3$ (SVSL of 257 $\mu g/m^3$);
- 1,3-butadiene at 200 $\mu g/m^3$ (SVSL of 14$\mu g/m^3$);
- benzene at 56 $\mu g/m^3$ (SVSL of 53 $\mu g/m^3$);
- bromodichloromethane at 56 $\mu g/m^3$ (SVSL of 11 $\mu g/m^3$);
- chloroform at 34 $\mu g/m^3$ (SVSL of 18 $\mu g/m^3$); and
- Freon 113 at 37,000,000 $\mu g/m^3$ (SVSL of 733,333 $\mu g/m^3$).

The highest reported concentrations of PCE and TCE (130,000 $\mu g/m^3$ and 11,000 $\mu g/m^3$, respectively) were from samples collected at the 15-ft bgs depth interval (Figures 7 and 8). At the deeper boring near the former plating shop, the highest reported PCE and TCE concentrations were both from samples collected at the 115-ft bgs depth interval (40,000 $\mu g/m^3$ PCE and 5,900 $\mu g/m^3$ TCE), with some samples collected at shallower depths also having PCE and TCE concentrations above respective SVSLs.

Soil gas detections measured in 2018 indicate that elevated PCE and TCE soil gas concentrations in the vadose zone appear to be largely contained within the footprint of the property at 900 Lake Havasu Avenue and extend vertically from near surface to groundwater. Other VOCs, while less frequently detected above SVSLs, show a similar pattern of localization at or in near vicinity to the former plating shop area.

3.2.3 Groundwater

The PCE plume is limited to the area near the former McCulloch facility buildings to approximately 100 feet downgradient, while the TCE plume extends from the former plating area to approximately 1,900 feet downgradient, to well LHH-02 (Figures 14 and 16). The maximum concentrations of PCE and TCE were 15 $\mu g/L$ and 17 $\mu g/L$, respectively, in 2020.

Two other VOCs, 1,1-DCE and 1,2-DCA, were detected in groundwater samples at concentrations exceeding their respective AWQS in 2020. However, 1,1-DCE exceeded its AWQS in a sample from only one well (MW-9), and 1,2-DCA exceeded the AWQS in samples from only two wells

(LHH-07 and I-3B). The maximum concentrations of 1,1-DCE and 1,2-DCA were 15 and 13 µg/L, respectively, in 2020.

The extent of the total chromium plume laterally extends from the area near the former plating area to approximately 3,000 feet downgradient, to beyond well LHH-02 (Figure 9). The maximum concentration of total chromium was 39,000 µg/L in 2020, over its AWQS of 100 µg/L.

The extent of nitrate in the aquifer is influenced by background concentrations in area groundwater, and based on nitrogen isotope analysis, unknown septic tanks or leaking sewage lines are likely contributing to the nitrate impacts observed in groundwater. The maximum concentration of nitrate in 2020 was 160,000 µg/L, over its AWQS of 10,000 µg/L.

3.3 Remedial Objectives

The ROs for the Site were developed by ADEQ pursuant to A.A.C. R18-16-406 (I) and were described in the RO Report that was contained in Appendix H of the RI Report. ROs are established for the current and reasonably foreseeable uses of land and waters of the state that have been or are threatened to be affected by a release of a hazardous substance. Pursuant to A.A.C. R18-16-406 (D), it is specified that reasonably foreseeable uses of land are those likely to occur at the site and the reasonably foreseeable uses of water are those likely to occur within one hundred years, unless site-specific information suggests a longer time is more appropriate.

The determination of reasonably foreseeable uses is based on information provided by water providers, well owners, landowners, government agencies, and others, for the Land and Water Use Study [LWUS], which was included as Appendix C in the RI Report. The ROs are based on the results of the LWUS and the associated solicitation of proposed ROs during a public meeting held in April 2020.

Pursuant to R18-16-406 (I)(4), the ROs must be stated in the following terms: (1) protecting against the loss or impairment of each use; (2) restoring, replacing, or otherwise providing for each use; (3) when action is needed to protect or provide for the use; and (4) how long action is needed to protect or provide for the use.

The following sections summarize the ROs established for the Site in the RO Report.

3.3.1 Remedial Objectives for Land Use

Because the property with the SRL exceedances is currently and will for the foreseeable future be zoned for non-residential use, non-residential SRLs apply. The minimum GPL for Cr(VI) is also exceeded in this location. Based on this information, the ROs for the soil for non-residential use to meet SRLs and to be protective of groundwater are as follows:

To restore soil conditions at the Lake Havasu Avenue and Holly Avenue Site to remediation standards for non-residential use as specified in A.A.C. R18-7-204 (background remediation standards), A.A.C. R18-7-205 (pre-determined remediation standards), or A.A.C. R18-7-206 (site-specific remediation standards) that are applicable to the hazardous substances identified to be impacting soils at the Lake Havasu Avenue and Holly Avenue Site. The concentrations remaining in soil after remediation standards are met will not cause or threaten to cause a violation of *groundwater remediation standards specified in A.A.C. R18-7-203. This action is needed for the present time and for as long as the level of soil contamination exceeds applicable cleanup standards.*

3.3.2 Remedial Objectives for Groundwater Use

Based on groundwater monitoring data, VOCs, total chromium, and nitrate exceed their respective AWQS in groundwater at the Site. Currently, groundwater within the Site is used as a potable water source. Therefore, the ROs for groundwater use at the Site are as follows:

Protect against the loss or impairment of potable water threatened by contaminants of concern at the Lake Havasu Avenue and Holly Avenue Site by restoring, replacing, or otherwise providing for potable water that is lost or impaired by contaminants of concern at the Lake Havasu Avenue and Holly Avenue Site. The actions will be needed for as long as necessary to ensure that, while the water exists and the resource remains available, the contamination associated with Lake Havasu Avenue and Holly Avenue Site does not prohibit or limit the designated use of groundwater.

3.3.3 Remedial Objectives for Surface Water Use

The closest surface water body to the Site is Lake Havasu. Lake Havasu City water supply is drawn from the lake approximately 2.25 miles from the Site. In addition, several large-scale water providers including the Central Arizona Project withdraw lake water approximately 21 miles down lake south of the Site. The lake is used for recreational activities including swimming, boating, watersports, and fishing. Surface water from Lake Havasu in the vicinity of the Site is not provided as drinking water.

Groundwater at the Site is likely hydraulically connected to the Lake Havasu/Colorado River system, although a pathway of Site COCs to surface water is considered incomplete as the Site COCs do not appear to have reached the lake. The surface water use is not currently considered threatened by the contamination at the Site; therefore, ROs for surface water use are not necessary.

4. IDENTIFICATION AND SCREENING OF REMEDIATION TECHNOLOGIES

This section presents the evaluation and screening of various remedial strategies and measures related to the impacts identified by the RI in soil, soil gas and groundwater, and lists the technologies that have been retained for evaluation as part of the reference and alternative remedies. A detailed discussion of the remediation technologies evaluated for potential implementation at the Site is provided.

4.1 Remedial Strategies

The Remedy Selection Rule, A.A.C. R18-16-407 (Feasibility Study), prescribes six remedial strategies to be developed, incorporating one or more remediation technologies or methodologies. These strategies are:

1. Plume remediation, a strategy to achieve water quality standards for COCs in waters of the state throughout the Site;
2. Physical containment, a strategy to contain impacts within definite boundaries;
3. Controlled migration, a strategy to control the direction or rate of migration but not necessarily to contain migration of the impacts;
4. Source control, a strategy to eliminate or mitigate a continuing source of impacts;
5. Monitoring, a strategy to observe and evaluate the impacts at the site through the collection of data; and
6. No action, a strategy that consists of no action at the Site.

4.2 Remedial Measures and Technologies Screening Assumptions

This section provides a discussion of the identification and screening of remediation technologies for potential implementation at the Site. Technologies are identified and screened separately for remediation of soil, soil gas and groundwater.

Remediation technologies that would meet site ROs and comply with requirements of A.A.C. R18-16-407 and A.R.S. §49-282.06 were identified and screened according to the following criteria:

- Contaminant treatment effectiveness;
- Constructability;
- Flexibility/expandability;
- Operations and maintenance (O&M) requirements;
- Operational hazards; and
- Cost-effectiveness.

The remediation technologies that passed screening were retained for use in development of the Reference Remedy and Alternative Remedies described in Section 5.

The following three subsections present the assumptions used during the identification and screening of remedial technologies.

4.3 Screening of Treatment Technologies

The remedial technologies commonly used for treating the Site COCs are described below. The basic treatment mechanisms and the suitability and limitations of the technologies are also discussed. An initial screening is presented below for each technology for applicability to Site conditions, the extent of COC impacts, and COC concentrations. Those technologies that were potentially applicable were then evaluated in detail using the technology screening criteria discussed above. The results of the initial technology screening are summarized in Table 1.

4.3.1 No Action

The No Action alternative assumes that no remediation efforts would be implemented for the Site, and that current conditions would continue. Impacted groundwater, vadose zone soil, and soil gas would not be remediated, potentially resulting in a continued source of COCs to groundwater and possibly a continued source of VOCs that may pose a potential vapor intrusion risk to building occupants. Under this alternative, impacted groundwater would not be remediated, potentially allowing further downgradient migration of Site COC plumes. As a result, under the No Action alternative, the ROs for the Site would not be met and this alternative is not retained.

4.3.2 Institutional/Engineering Controls

Institutional controls such as land use restrictions are commonly utilized for sites where residual soil impacts may exist and the future use of a property is likely to be commercial or industrial. Engineering controls can consist of actions such as fencing or capping. A.R.S. §49-152 allows for the use of institutional or engineering controls to meet the requirements of that section; however, a Declaration of Environmental Use Restriction (DEUR) would have to be placed on the areas of the property that remain exceeding residential SRLs. The use of institutional and engineering controls along with a DEUR can be a cost-effective means of obtaining site closure.

Institutional and engineering controls are retained as a remedial alternative for Site soils, in conjunction with other remedial measures, with the possibility of a DEUR in the future if groundwater is shown to no longer be impacted by the soils in the source area.

4.3.3 Soil Vapor Extraction

Soil vapor extraction (SVE) is an established remedial technology for treatment of VOCs in the vadose zone. SVE involves the installation of SVE wells in impacted vadose zone soil and then applying vacuum to extract soil vapors containing VOCs from these wells. The extracted soil vapor can then be discharged to the atmosphere following treatment as needed to remove VOCs, depending on the quantity emitted and local regulations. SVE is effective for source mitigation to prevent groundwater impacts from vadose zone VOCs, but SVE does not directly attenuate existing groundwater impacts.

The RI Report indicates that VOCs, including PCE and TCE, were detected in soil gas under the building located at 900 North Lake Havasu Avenue at concentrations in exceedance of SVSLs; therefore, SVE could be utilized as a remedial measure to address potential risk associated with soil vapor intrusion by reducing VOC mass in soil gas. This remedial technology is considered feasible and implementable with respect to the design and operation of an SVE system at the Site. Given that its effectiveness is only applicable to address soil gas impacts from VOCs, SVE would not be considered a stand-alone remedial measure; rather, it would be used in combination with other remedial measures as necessary. For this reason, SVE is retained as a treatment technology for remediating VOC-impacted soil gas at the Site, in conjunction with other remediation strategies.

4.3.4 Monitored Natural Attenuation

Monitored natural attenuation (MNA) is a widely applied remedial measure at sites where natural processes are expected to reduce COC concentrations over time. Such natural processes include dilution, dispersion, sorption, volatilization, and chemical and/or biological stabilization or transformation. For chlorinated VOCs, such as PCE and TCE, natural reductive dechlorination (via biological and/or abiotic degradation processes) can be a significant degradation process when conditions are favorable (i.e., anaerobic environments with available organic carbon). Similarly, under the same favorable conditions, Cr(VI) and nitrate can also both undergo natural microbiological transformation to more benign compounds, specifically trivalent chromium [Cr(III)] and nitrogen gas.

Application of MNA requires the identification of the most likely attenuation processes and an estimation of the time required for these processes to meet the remedial objectives. MNA also includes implementation of a plan to observe the progress of the remedy to monitor that natural attenuation proceeds, and that unexpected migration of impacts does not occur.

Groundwater parameters observed in recent monitoring events indicate that mildly reducing conditions are present in portions of the impacted aquifer; e.g., oxidation-reduction potential values reported for some Site monitoring wells and several LHC production wells were generally negative during 2018 monitoring, and many of these wells exhibited low or near-anaerobic oxygen levels. Mildly reducing conditions indicate the aquifer is generally conducive to attenuation of Site COCs through processes such as reductive dechlorination of PCE and TCE, denitrification of nitrate, and through reduction of Cr(VI) to less toxic and insoluble Cr(III). Additionally, other abiotic MNA processes (e.g., dilution, dispersion, and sorption) may result in dissolved-phase COC concentrations decreasing to less than applicable AWQS levels over time without the presence of an ongoing source of new COC impacts to groundwater.

MNA may not be sufficiently protective of groundwater users in the event that groundwater pumping activities were to take place downgradient of COC impacts (e.g., if LHC were to resume active pumping from the LHC production wells).

MNA is frequently included as a component in a larger remedial strategy and is commonly coupled with active remediation at source areas. Given that groundwater conditions are generally conducive to natural attenuation of all Site COCs, MNA is considered capable of achieving the applicable groundwater ROs for the Site and is retained as a treatment technology for Site groundwater, in conjunction with other remediation strategies.

4.3.5 Groundwater Extraction and Treatment

A groundwater extraction and treatment system (GETS) is a technology for groundwater remediation that can be effective for hydraulic containment and/or migration control for sites impacted by dissolved-phase COCs. Extraction and treatment systems, colloquially referred to as “pump and treat”, typically utilize submersible pumps in extraction wells to extract groundwater and transfer it via conveyance piping into an aboveground treatment system. The post-treatment water is subsequently discharged to a municipal sewer, a canal or other surface water, an infiltration basin, or re-injected into the subsurface with an injection well. These systems can control the subsurface flow of impacted groundwater, mitigating migration and/or reducing the footprint of the impacts.

A variety of ex situ water treatment systems are employed to provide appropriate treatment of extracted water and are selected based on the type and concentration of the COCs in question. Liquid-phase granular activated carbon (LGAC) is typically employed for VOC removal via adsorption onto the media surface, while ion exchange resin is commonly employed for the removal of soluble metals (such as Cr[VI]) and nitrate. The design of a GETS for the Site would need to consider requirements for discharge of treated water, e.g., treatment to below AWQSs for discharge into the Kiowa Wash.

The primary limitation for GETS is typically long cleanup times when used as the primary remedial measure in heterogeneous formations where diffusion from fine-grained layers provides a secondary source. As a dissolved-phase plume treatment alternative, GETS is not typically cost effective for large, dilute plumes. However, GETS is a widely implemented and proven component for source mitigation of localized, high-concentration groundwater impacts or plume migration control.

This technology is implementable with respect to both the design and operation of a treatment system and is amenable to the hydrostratigraphy of the Site and is therefore considered capable of achieving the ROs for groundwater. Therefore, GETS technology is retained as a remedial measure for additional evaluation.

4.3.6 In Situ Chemical Reduction

In situ chemical reduction (ISCR) can abiotically reduce COC concentrations by chemically breaking the bonds within the VOC molecules and reducing metal contaminants to a less soluble state using chemical reductants. In this assessment, the reductants zero-valent iron (ZVI), calcium polysulfide (CaS_x) and hydrogen sulfide (H_2S) were evaluated for effectiveness in treating one or more Site COCs.

ZVI has not been proven to be reliably effective for Cr(VI) treatment, though it has well-established effectiveness for most chlorinated VOCs and nitrate. Additionally, injection of ZVI is anticipated to be difficult due to the Site geology and depth to groundwater. For these reasons, this technology was not retained for further consideration.

As indicated in the RI Report, CaS_x was previously evaluated for effectiveness in treating Cr(VI) at the Site; results from that assessment indicated limited effectiveness for this treatment method. Additionally, CaS_x has not been proven to be reliably effective for Site COCs other than Cr(VI), and injection of CaS_x is anticipated to be difficult due to the Site geology and depth to groundwater. For these reasons, this technology was not retained for further consideration.

In addition to the liquid-based reductants described above, the gaseous reductant H_2S was evaluated for potential effectiveness in treating vadose zone soil and groundwater impacted by Site COCs. While this technology has been proven effective in treating Cr(VI), its effectiveness for other Site COCs is not established. Additionally, H_2S is a toxic gas, and injection of this reductant into vadose zone soil may potentially result in migration of the gas to surface, posing a potential inhalation risk. Therefore, due to the hazards associated with this technology and the limited effectiveness for treating COCs other than Cr(VI), this technology was not retained for further consideration.

Based on the limitations and concerns described above, ISCR technology was not retained for further consideration.

4.3.7 In Situ Chemical Oxidation

In situ chemical oxidation (ISCO) can abiotically oxidize VOC concentrations by chemically breaking the bonds within the VOC molecules using chemical oxidants. However, oxidation of metals like chromium can lead to mobilization of hexavalent chromium. ISCO is not recommended at this site as it would likely expand the chromium plume significantly. In addition, the naturally reducing conditions observed in the local aquifer would be difficult to overcome for this remedial technology to be effective for remediation of the VOCs at the Site. Therefore, this remedial technology is not retained for further consideration.

4.3.8 In Situ Bioremediation

In situ bioremediation (ISB) involves stimulation or augmentation of naturally-occurring microbial populations to expedite the biodegradation or attenuation of COCs through subsurface injections of electron donor (e.g., high fructose corn syrup [HFCS] or emulsified vegetable oil [EVO]). In the presence of sufficient electron donor, natural microbial activity will produce the required anaerobic and reducing conditions conducive to biodegradation and attenuation of Site COCs: reductive dechlorination of PCE and TCE, denitrification of nitrate to nitrogen gas, and reduction of Cr(VI) to less toxic and insoluble Cr(III).

Successful implementation of ISB includes adequate distribution of the electron donor to achieve reducing conditions, relatively neutral pH conditions, and low concentrations of competing electron acceptors, such as sulfate. Based on recent groundwater monitoring results, mildly reducing conditions are present in portions of the impacted aquifer; therefore, the prevailing condition appears to be conducive to biodegradation or attenuation of all Site COCs that exceed AWQS (total chromium, VOCs [primarily PCE and TCE], and nitrate). As such, ISB appears to be well suited as a Site remedial alternative as electron donor dosing would be based on maintaining or further reducing the already prevailing condition in Site groundwater, to promote the desired bioremediation for COCs.

Results at the Site indicate this remedial technology will likely be highly effective for treating the COCs in groundwater and is implementable under Site conditions. Within five months of injections of a HFCS and EVO mixture nearby, results from monitoring well LHH-08 showed a 98% drop in chromium concentrations (1,500 µg/L to 26 µg/L) and a 99% reduction in nitrate concentrations (15,000 µg/L to <50 µg/L). Other nearby monitoring wells saw chromium reductions between 51 and 7% and nitrate reductions between 62 and 6%.

Microbial community analysis of Site groundwater showed that chromium reducing microorganisms such as *Geobacter* and *Cupriavidus*-related bacteria were present. In areas near to the injection point, *Geobacter* related genes ranged from $5x10^3$/L in LHH-07 to 2 x 10^7/L in LHH-08. In addition, gene analysis of the groundwater samples showed that all samples contained low to moderate concentrations of denitrifying bacteria genes, ranging from 1 x 10^3/L to 7 x 10^6/L.

Therefore, based on the results that support this remedial alternative, including the mildly reducing conditions and the microorganisms already present for ISB in Site groundwater, ISB is considered capable of meeting groundwater ROs for the Site and is retained for further consideration.

4.3.9 Wellhead Treatment for LHC Municipal Wells

Wellhead treatment for production wells is a commonly used technology for meeting drinking water standards. The size, scale, and specific treatment technologies employed in the water treatment depends on the volume of water produced and the condition of pumped groundwater prior to treatment. Commonly used treatment technologies include filtration and sterilization, and in some cases sorption, ion exchange, or other technologies.

This remedial alternative may be a required contingency measure if, for example, MNA were to be the selected remedy for the Site, and natural attenuation processes were inadequate to effectively biodegrade or attenuate Site COCs prior to plume migration to the vicinity of the LHC production wells, causing COCs in the wells in exceedance of AWQS. If implemented, one or more treatment technologies (e.g., filtration, sorption, ion exchange, disinfection, etc.) would likely be necessary to treat water extracted from LHC production wells to a potable water standard. The specific water treatment technologies required would be determined based on the specific Site COC(s) potentially impacting the wells; however, for planning purposes, it is assumed that chromium and nitrate would be the contaminants requiring treatment, and the VOC plumes are small and unlikely to reach the LHC production wells.

For purposes of evaluation of this technology as a remedial alternative, it was assumed that the total pumping rate of a LHC production well would be approximately 1,000 gallons per minute (gpm). Based on this flowrate and conservative estimates of COC concentrations, wellhead treatment at LHC production wells is considered implementable and capable of achieving the ROs for groundwater. Therefore, this technology is retained as a remedial measure for further consideration.

Table 1: Remediation Technology Screening Summary

Technology	Retained	Reason
No Action	No	Would not meet ROs for the Site.
Institutional/Engineering Controls	Yes	For the source area, maintenance of concrete/asphalt barriers are important to keep receptors from being exposed to shallow soil contamination. A DEUR may be implemented after groundwater contamination/threat to groundwater is addressed.
Soil Vapor Extraction	Yes	Remedial technology considered practicable and effective for removing VOC mass from vadose zone.
Monitored Natural Attenuation	Yes	Will likely be able to meet ROs when used in conjunction with other groundwater remediation technologies.
Groundwater Extraction & Treatment System	Yes	Can effectively address all COCs in groundwater, cuts-off plumes and prevents further downgradient migration of COCs from the source area.
In Situ Chemical Reduction	No	Technically and economically infeasible due to mixture of contaminant types, thickness of impacted groundwater zone and the size and depth of the plumes. Some specific reductants pose hazards.
In Situ Chemical Oxidation	No	Would likely make chromium contamination increase. Site groundwater is naturally reducing.
In Situ Bioremediation	Yes	Previously evaluated at Site and proven effective for all COCs in groundwater. Most likely to provide rapid attenuation of COCs at both downgradient plume and source area, likely shortening time to achieve groundwater ROs.
Wellhead Treatment	Yes	Would be protective of LHC municipal wells, if these wells were at risk due to COCs in exceedance of AWQS.

5. DEVELOPMENT OF REFERENCE REMEDY AND ALTERNATIVE REMEDIES

This section presents the developed Reference Remedy along with two alternative remedies (the More Aggressive Remedy and the Less Aggressive Remedy), all of which were selected from the retained remedial technologies described in Subsection 4.3. Evaluations of the alternatives include a discussion of the associated remedial measures and strategies pursuant to A.A.C. R18-16-407 (E). The reference and alternative remedies for the impacts are summarized in Table 2.

The Reference Remedy and Alternative Remedies consist of combinations of remedial strategies and their associated remedial measures, selected to achieve the ROs for the site. The remedies also include contingent remedial strategies (contingencies) to address reasonable uncertainties regarding the achievement of ROs, or uncertain timeframes in which ROs will be achieved. Where remedial measures are necessary to achieve ROs, such remedial measures will remain in effect as long as required for continued achievement of those objectives.

Remedial strategies may incorporate more than one remediation technology or methodology. As provided in A.A.C. R18-16-407(F), remedial strategies are:

- Plume remediation to achieve water quality standards for COCs in waters of the state throughout the Site;
- Physical containment to contain contaminants within definite boundaries;
- Controlled migration to control the direction or rate of migration, but not necessarily to contain migration of contaminants;
- Source control to eliminate or mitigate a continuing source of contamination;
- Monitoring to observe and evaluate the contamination at the Site through the collection of data; and
- No action.

For soil, potential remedies consider future land use and potential risk exposure through vapor intrusion or impacts to groundwater. For groundwater, potential remedies have been identified with consideration of the needs of the water provider (LHC) and its customers, including the quantity and quality of water and operational implications. Where remedial measures are necessary to achieve ROs, the remedial measures will remain in effect as long as required for continued achievement of those objectives.

The Reference Remedy and each Alternative Remedy may also include contingent remedial measures to address reasonable uncertainties regarding the achievement of ROs, or uncertain timeframes in which ROs will be achieved. Decision points for each contingency will be determined in the Proposed Remedial Action Plan, to be prepared following issuance of this FS Report. The Reference Remedy and the Alternative Remedies for soil and groundwater are summarized below, and detailed descriptions are presented in Subsections 5.1 to 5.3.

For the soils, the three remedies are proposed as follows:

Reference Remedy – An SVE system installed at the warehouse building located at 900 North Lake Havasu Avenue, conceptually comprised of SVE wells, soil vapor probes, an SVE blower and treatment system and related conveyance piping, with up to four years of planned operation. The current concrete/asphalt near to the former plating area is assumed to be maintained by the current property owner to prevent exposure to their employees/visitors.

More Aggressive Remedy Soil remedial measures for the More Aggressive Remedy are the same as for the Reference Remedy but include the implementation of ISB at the source area. ISB will be used to remediate impacted vadose zone soil directly above the saturated interface, which may be a source of COCs to groundwater if groundwater level rises further in the future.

Less Aggressive Remedy – Soil remedial measures for the Less Aggressive Remedy are the same as for the Reference Remedy.

For groundwater, the three remedies are as follows:

Reference Remedy – A GETS installed downgradient of the source area in the vicinity of Highway 95. The GETS will conceptually consist of two extraction wells connected to a water treatment system including filtration, LGAC, and ion exchange resin technologies designed to treat up to 200 gpm of extracted water to below AWQSs, conveyance piping from the extraction wells to the treatment system, and associated infrastructure. Treated water may be discharged to the Kiowa Wash or local sewer. For FS costing purposes it was assumed the GETS would operate for 30 years, with 30 years MNA to address the diffuse plume beyond the location of the treatment system and any residual contamination after system shutdown. These timeframes would be refined prior to remedy selection with pilot testing/modelling, if needed. A contingency is included for limited ISB near to the source area if needed to ensure groundwater ROs are met within the MNA timeframe.

More Aggressive Remedy – An ISB system conceptually consisting of 16 injection wells (five wells at the source area and 11 downgradient wells), an ISB system compound (for electron donor storage, pumps, and related infrastructure) and conveyance piping from the compound to the wells. Six of the downgradient ISB injection wells are already installed along the right-of-way of Highway 95. The anticipated location for the other five downgradient injection wells is in the vicinity of Lake Havasu Avenue, while the source area wells will most likely be sited in close proximity to the former facility operation areas. Once the ISB system installation is completed, a four-year ISB injection program will then be initiated. MNA for nine years is included to address any remainder of the plume, and a contingency for installation of wellhead treatment for LHC production wells, if it is determined that COCs in exceedance of AWQS have been detected in the LHC production wells point of compliance monitoring.

Less Aggressive Remedy – MNA of the COC plumes, planned for at least 30 years, and a contingency for installation of wellhead treatment for LHC production wells, if it is determined that COCs in exceedance of AWQS have been detected in the LHC production wells point of compliance monitoring.

5.1 Reference Remedy

5.1.1 Plume Remediation and Controlled Migration

Under the Reference Remedy, plume remediation will be achieved through use of a GETS and MNA. Operation of the GETS will achieve COC plume remediation through removal of dissolved-phase COC mass from the COC plumes and subsequent treatment using appropriate ex situ water treatment technologies. Additionally, dilute groundwater impacts will be mitigated by natural attenuation in the limited dilute portions of some COC plumes that may be at the plume periphery or downgradient of the GETS at time of implementation.

Controlled migration will be achieved by the GETS through active groundwater extraction to prevent downgradient migration of the plume.

5.1.1.1 Reference Remedy – GETS

Implementation of a GETS for the Reference Remedy will conceptually comprise the following:

- Installation of up to two six-inch diameter groundwater extraction wells designed to intercept and hydraulically control migration of the COC plumes, mitigating further downgradient migration;
- Installation of a water treatment system with a capacity of at least 200 gpm to accommodate the anticipated flow rates from the extraction wells; the water treatment system will utilize filtration, LGAC and ion exchange resin technologies to ensure effective treatment of all COCs in the plumes to below AWQSs;
- Installation of conveyance piping from the extraction wells to the water treatment system; and
- Operation, maintenance, and monitoring to assess remedial progress and system performance.

The GETS will conceptually include up to two groundwater extraction wells anticipated to be located in the vicinity of Highway 95 (Figure 19). The capture zone is based on capture analysis of an 8-hour step-drawdown test and 24-hour constant rate pumping test performed on MW-21 (URS, 2001), and geotechnical analysis collected from the transect borings along Highway 95 (Geosyntec and ADEQ, 2020). The wells will be spaced and sited to bisect and capture the portions of the COC plumes that exceed AWQS. Well screen lengths and elevations for the extraction wells will be determined based on the specific locations these wells are sited, with the objective of capturing the highest concentration component of the COC plumes.

The GETS will also include the installation of a water treatment system. Groundwater conveyance piping will be installed to convey extracted groundwater from the wells to the water treatment system. The anticipated flow rate of groundwater extraction is approximately 100 gpm from each well, or a total of 200 gpm for the system in its entirety.

Anticipated ex situ water treatment for the GETS includes filtration, LGAC and ion exchange resin technologies, which will be designed to treat water to below AWQSs so that treated water may then be discharged to the Kiowa Wash or local sewer. For costing purposes, it is assumed that the water treatment system and its component features will be placed on a slab-on-grade foundation anticipated to be approximately 40-ft by 40-ft in size, which will be secured with perimeter fencing.

This remedy will treat all groundwater COCs, cut off the plumes, and inhibit migration of COCs from the source area to locations downgradient of the GETS. This remedy will not directly address the source area; therefore, it will likely require an extended period of time to ultimately mitigate the elevated impacts found near the source area, with natural attenuation mitigating the dilute impacts further downgradient. For costing purposes, it is assumed that the GETS will be operated, maintained and monitored for a 30-year period. As indicated in Subsection 5.1.4, for contingency planning, it is assumed that ISB will be implemented at the source area as a contingency remedial measure if it is determined during the first or any subsequent periodic site review that the anticipated operation of the GETS would be greater than 30 years to achieve groundwater ROs.

5.1.1.2 Reference Remedy – MNA

Due to the large area covered by some COC plumes, the application of MNA is appropriate for the peripheral dilute portions of the plumes where the COCs are reasonably anticipated to be attenuated by natural processes (e.g., dilution and dispersion) downgradient of the GETS. Additionally, due to the mildly reducing conditions and the microbial communities already present in the aquifer, MNA-associated biological processes such as reductive dechlorination, denitrification and Cr(VI) reduction are likely mechanisms that will contribute to reduction of COC concentrations in the plumes over time. For FS purposes, it was assumed that MNA will be performed for a 30-year period.

5.1.2 Source Control

Under the Reference Remedy, soil remedial measures (SVE system operation) for source control will be implemented to mitigate VOC impacts to soil gas where exceedances of applicable SVSLs are present. The source area paving that is maintained by the property owner is also a source control to prevent further infiltration of chromium in the soil.

5.1.2.1 Reference Remedy – Source Area Paving

For the source area, the existing concrete and asphalt barriers will be maintained to prevent potential receptors from being exposed to shallow soil contamination. A DEUR may be implemented after groundwater contamination/threat to groundwater is addressed. The property owner will be responsible for maintaining the existing concrete and asphalt barriers and obtaining a DEUR.

5.1.2.2 Reference Remedy – SVE

Implementation of SVE for the Reference Remedy will conceptually comprise the following:

- Installation of five SVE wells installed at locations inside and around the perimeter of the building at 900 North Lake Havasu Avenue. In addition, ten soil vapor probes will be installed to monitor the SVE performance (Figure 20). A sixth SVE well and two additional soil vapor probes will also be installed, in locations to be determined based on field observations; and

- Installation of an SVE blower/treatment system and associated components (conveyance piping, manifold, filter, air/water separator, treatment vessels, etc.) with sufficient treatment capacity to support the active remediation of all six SVE wells. For costing purposes, it is assumed that the SVE blower/treatment system will be placed on a slab-on-grade foundation anticipated to be approximately 20-ft by 20-ft in size, which will be secured with perimeter fencing.

Operation of the SVE system will provide source control through the removal of VOC mass in the vadose zone, which will mitigate the potential for vapor intrusion from the residual VOCs within the vadose. For the purpose of this FS, it is assumed that the SVE system for the Reference Remedy will be operated for up to four years, or until the vadose zone is either remediated or asymptotic decreases in soil vapor VOC concentrations are observed. SVE system optimization will be conducted throughout the four-year operation period, and operational schedules may be adjusted to enhance VOC removal. After SVE system shut-down, VOCs will be monitored for rebound for a period of three months, after which confirmation soil vapor samples will be collected to support achieving the ROs and discontinued SVE operations.

5.1.3 Monitoring

Implementation of monitoring for the Reference Remedy will conceptually comprise the following:

- Semiannual soil vapor sampling from SVE wells and from soil vapor probes;
- Semiannual sampling of the groundwater monitoring well network to evaluate plume stability, COC concentrations, and natural attenuation parameters; and
- Semiannual groundwater elevation measurements to evaluate flow direction and hydraulic gradient.

Semiannual groundwater monitoring of the current monitoring well network (40 wells, as of the 2020 annual groundwater monitoring event) is anticipated to be performed under the present sampling and analytical regime for as long as the GETS is in operation or until groundwater ROs have been achieved. For FS purposes, it is assumed that monitoring will be performed on a semiannual basis for 30 years. The scope and/or frequency of groundwater monitoring may be adjusted based on results obtained through semiannual monitoring; any adjustments will be implemented only after prior approval from ADEQ.

5.1.4 Contingencies

Contingencies for the Reference Remedy include the following:

<u>Source Area Remediation Contingencies</u>

- ISB may be implemented at the source area if it is anticipated that an excessive period of time will be required before groundwater ROs are achieved. It is assumed herein that if during a periodic site review it is determined that the GETS operation will not achieve groundwater ROs within the planned 30-year operational timeframe, then ISB will be implemented as a source area remedial measure to reduce COC mass and decrease the time until ROs are achieved. If this contingency measure is implemented then it will be performed in a manner consistent with that described for source zone ISB (i.e., mounding ISB) in Subsection 5.2.1.1. For FS costing purposes, it is assumed that ISB contingency may be implemented for two years after the five-year periodic site review.

Plume Remediation Contingencies

- Additional GETS runtime; for planning and budgeting purposes, it is assumed that an additional five years of GETS operation and groundwater monitoring may be needed.

5.2 More Aggressive Remedy

5.2.1 Plume Remediation

Under the More Aggressive Remedy, plume remediation will be achieved through implementation of ISB and MNA. ISB will reduce the concentrations of all COCs in the plumes, including at locations of the plumes in vicinity of the source area as well as at downgradient extents. Additionally, dilute groundwater impacts at the peripheral extents of the plumes will be mitigated by natural attenuation in the limited portions of the plumes that may be downgradient of areas where ISB will be implemented.

5.2.1.1 More Aggressive Remedy – ISB

Implementation of ISB for the More Aggressive Remedy will conceptually comprise the following:

- Installation of five additional ISB injection wells to compliment the six wells already installed downgradient of the source area;
- Installation of five ISB injection wells located at the source area, in the vicinity of the former plating shop at the former McCulloch facility;
- Installation of an ISB system compound for placement of electron donor storage tanks, pumps, manifold assemblies and other components and infrastructure associated with the ISB system;
- Installation of conveyance piping from the ISB system compound to the injection wells, for conveyance of electron donor solution;
- Integration of any ISB wells/system installed prior to the signing of the Record of Decision; and
- Operation, maintenance, and monitoring to assess remedial progress and system performance.

The conceptual ISB system will include 16 injection wells; 11 wells will be located at areas downgradient of the source area, and five wells will be located in the immediate vicinity of the source area (Figure 21). Wells are anticipated to be 4-inch diameter with screen lengths of approximately 40-feet. Screen interval elevations will be determined based on vertical plume extents, with the objective being to target the highest concentration component of the COC plumes at any given well location.

While the actual locations of the wells will be dependent on factors including land availability, existing infrastructure, and relative location to the COC plumes, it is anticipated that the 11 downgradient injection wells will be sited in the vicinity of the right-of-way adjacent to State Route 95 and Lake Havasu Avenue. Six of these wells along Highway 95 have already been installed at the Site.

The five injection wells planned for the source area are anticipated to be sited in the area near to the former plating shop, taking into account accessibility, existing infrastructure, and property availability. These injection wells will be designed to address the highest concentration portions of the COC plumes and will also be used to treat COC impacts to vadose zone soil directly above the saturated interface. The latter objective will be achieved by inducing mounding of the groundwater table during the injection process. The intent of the mounding will be to promote contact between injectate solution and impacted vadose zone soil directly above the saturated interface, thus treating the portion of the vadose zone which is a potential source of COCs to groundwater if groundwater level rises further in the future.

If deemed necessary, naturally degradable viscosity-modifying agents (e.g., guar gum) may be added to the injectate solution at the five source area wells, to further promote and/or increase the extent of mounding. If utilized, these agents would be used only in specific circumstances, and only if unamended injectate solution (i.e., without viscosity-modifiers) was shown to induce an insufficient degree of mounding.

An ISB system compound will be constructed at a location as central as possible to the source area and downgradient injection wells (land availability permitting). The compound is anticipated to incorporate a slab-on-grade foundation and will be used to site tank storage for electron donors, transfer and mixing pumps, manifolds for controlling donor solution conveyance, Dosatron® injectors for controlling injectate solution concentration (i.e., donor:water ratios), connections to LHC-provided potable water, and other components of the ISB system. The compound foundation is anticipated to be approximately 50-ft by 50-ft in size, which will be secured with perimeter fencing.

Once the ISB system installation is completed, a four-year ISB injection program will then be initiated, which will include concurrent semiannual groundwater monitoring. Data collected at the Site demonstrated that the addition of approximately 18,000 gallons of HFCS and EVO reduced chromium and nitrate concentrations by 98% and 99%, respectively, within approximately 30 feet of the injection location. Additionally, strong indications of bioremediation of the target COCs were also observed approximately 185 feet downgradient of the injection location, while redox effects and limited reduction of COCs were observed nearly 635 feet downgradient. Based on these results, it is anticipated that up to 3,000,000 gallons of electron donor solution could be needed for injection into the array of ISB wells over the course of each year to remediate the targeted plume areas. This estimate is based on work previously completed at the Site. The donor solution may contain both a rapidly-degradable electron donor substrate (e.g., HFCS) and a longer-acting electron donor substrate (e.g., EVO). Specific dosing and injectate solution concentrations will be determined based on well locations, monitoring data and other considerations. For FS costing purposes, it was assumed the concentrations would be approximately 1% to 2% by volume of each respective donor. Potable water provided by LHC will be used to formulate the donor solutions, which may include a deoxygenating agent if needed.

This remedy will treat groundwater with the highest COC concentrations (i.e., at the source area), bisect and cut off the plumes, and inhibit migration of COCs from the source area to locations downgradient of the ISB system, with natural attenuation mitigating the dilute impacts further downgradient. For FS planning and budgetary purposes, it is assumed that an additional five-years of semiannual groundwater monitoring will be performed after the conclusion of the planned four-year ISB injection program, to assess COC concentrations and to monitor for potential rebound during the post-injection period.

Based on the results from the Site and the conceptual ISB design described herein, this remedy is considered highly practicable and implementable, and is considered the most effective and efficient remedy to achieve groundwater ROs in the shortest duration of time. This remedy should result in significant COC concentration reductions throughout the plumes; however, for contingency planning, it is assumed that well head treatment at up to two of the LHC production wells may be needed if COCs in exceedance of AWQS are detected in the LHC production wells point of compliance monitoring.

5.2.1.2 More Aggressive Remedy – MNA

Due to the large area covered by some COC plumes, the application of MNA is appropriate for the peripheral dilute portions of the plumes where the COCs are reasonably anticipated to be attenuated by natural processes (e.g., dilution and dispersion) downgradient of the ISB injection wells. Additionally, due to the mildly reducing conditions present in the aquifer and the microorganisms already present for ISB in groundwater, MNA-associated biological processes such as reductive dechlorination, denitrification and Cr(VI) reduction, are likely mechanisms that will contribute to reduction of COC concentrations in the plumes over time; these biological processes are likely to be enhanced by the ISB system, as electron donor migrates into more distal portions of the plumes. For FS purposes, it is assumed that nine years of MNA will be performed (four years during the ISB program and five additional years thereafter).

5.2.2 Source Control

5.2.2.1 More Aggressive Remedy – SVE

The SVE component of the vadose zone source control remedial measures for the More Aggressive Remedy are the same as for the Reference Remedy (Subsection 5.1.2.2).

5.2.2.2 More Aggressive Remedy – ISB

Source control will also be achieved through use of ISB, as described in Subsection 5.2.1.1. ISB will be used for source control of the saturated zone and the vadose zone soil directly above the saturated interface in the vicinity of the source area by mounding injectate.

5.2.2.3 More Aggressive Remedy – Source Area Paving

The maintenance of source area paving is the same as for the Reference Remedy.

5.2.3 Monitoring

Implementation of monitoring for the More Aggressive Remedy will conceptually comprise the following:

- Semiannual soil vapor sampling from SVE wells and from soil vapor probes;
- Semiannual sampling of the groundwater monitoring well network to evaluate plume stability, COC concentrations, and natural attenuation parameters; and
- Semiannual groundwater elevation measurements to evaluate flow direction and hydraulic gradient.

Semiannual groundwater monitoring of the current monitoring well network (40 wells, as of the 2020 annual groundwater monitoring event) is anticipated to be performed under the present sampling and analytical regime throughout the planned four-year ISB injection program. For FS purposes, it is assumed that an additional five years of semiannual groundwater monitoring will be performed after the conclusion of the planned four-year ISB program (for a total of nine years of monitoring), to evaluate COC concentrations, monitor for potential rebound during the post-injection period, and assess the achievement of groundwater ROs. The scope and/or frequency of groundwater monitoring may be adjusted based on results obtained through semiannual monitoring; any adjustments will be implemented only after prior approval from ADEQ.

5.2.4 Contingencies

Contingencies for the More Aggressive Remedy include the following:

Plume Remediation Contingencies

- If plume remedial measures are found to be insufficient to prevent plume migration to LHC production wells and COC concentrations in exceedance of AWQS are detected at the point of compliance for the LHC production well, then wellhead treatment for the impacted well may be implemented. Two LHC wells have historically had detections of site COCs over AWQS after periods of use of the northern wellfield. Therefore, two wellhead treatment systems are included in the contingency. If this contingency is needed, then the specific design of the wellhead treatment system would be determined based on requirements for capacity and treatment efficacy at that time. For costing, it is assumed that the wellhead treatment would need to be in place for ten years.

5.3 Less Aggressive Remedy

5.3.1 Plume Remediation

Under the Less Aggressive Remedy, plume remediation will be achieved through MNA; the aforementioned mildly reducing conditions and microbial communities already present in portions of the aquifer are anticipated to reduce concentrations of all COCs through natural microbiological processes. Relatedly, other natural processes (e.g., dilution and dispersion) will also promote reductions in COC concentrations in the plume over time.

5.3.2 Source Control

Vadose zone source control remedial measures (SVE system operation and source area paving) for the Less Aggressive Remedy are the same as for the Reference Remedy (Subsection 5.1.2).

5.3.3 Monitoring

Implementation of monitoring for the Less Aggressive Remedial Remedy will conceptually comprise the following:

- Semiannual soil vapor sampling from SVE wells and from soil vapor probes;
- Semiannual sampling of the groundwater monitoring well network to evaluate plume stability, COC concentrations, and natural attenuation parameters;
- Semiannual groundwater elevation measurements to evaluate flow direction and hydraulic gradient; and
- Installation of two additional monitoring wells to ensure full monitoring of the plumes in the future.

Semiannual groundwater monitoring of the current monitoring well network (40 wells, as of the 2020 annual groundwater monitoring event) is anticipated to be performed under the present sampling and analytical regime until groundwater ROs have been achieved (Figure 22). For FS purposes, it is assumed that monitoring will be performed on a semiannual basis for 30 years. However, as part of this remedy, a groundwater flow and transport model and natural attenuation model will be completed to estimate the extent of COC impacts over time. The model will also account for the contingency scenario that LHC may begin pumping from its production wells located west of the Site, which would likely alter the ambient groundwater gradient in vicinity of the Site. The groundwater model will be updated every five years to re-evaluate the timeline for COC natural attenuation to concentrations below AWQS.

The scope and/or frequency of groundwater monitoring may be adjusted based on results obtained through semiannual monitoring; any adjustments will be implemented only after prior approval from ADEQ.

5.3.4 Contingencies

Contingencies for the Less Aggressive Remedy include the following:

<u>Plume Remediation Contingencies</u>

- If MNA is found to be insufficient to prevent plume migration to the LHC production wells located west of the Site, and COC concentrations in exceedance of AWQS are detected in the wells, then wellhead treatment may be installed at the impacted LHC wells. The treatment system would include appropriate treatment technology adequate to meet potable water standards for treated water. For the purpose of this FS, it is assumed that two LHC wells may need treatment, and that the wellhead treatment will be in operation for 30 years; and

- ISB may be implemented if MNA is found to be insufficient to prevent plume migration to the LHC production wells located west of the Site and COC concentrations in exceedance of AWQS are detected in the wells, or if it is anticipated that an excessive period of time will be required before groundwater ROs are achieved. If this contingency measure is implemented, then it will be performed in a manner consistent with that described in Subsection 5.2.1.1. For FS costing purposes, it is assumed that ISB contingency will be implemented for two years.

6. COMPARISON OF REMEDIES

Table 2 presents a detailed evaluation of the remedies for COC impacts in the soil and groundwater with respect to achieving ROs, consistency with land and water use plans, and the comparison criteria. The following subsections detail how the remedies perform against these criteria.

6.1 Achievement of Remedial Objectives

Soil: The Reference, Less Aggressive, and More Aggressive remedies will achieve ROs for soils at the Site by providing source control through removal of VOC mass in the vadose zone, and by ensuring that the COC remaining in soil will not cause or threaten to cause a violation of groundwater remediation standards specified in A.A.C. R18-7-203. Additionally, maintenance of existing hardscape will mitigate the potential exposure pathways associated with soil contamination.

Groundwater: The Reference, Less Aggressive, and More Aggressive remedies will achieve ROs for groundwater at the Site by protecting against the loss or impairment of potable water threatened by COCs at the Site by remediating groundwater.

6.2 Consistency with Land Use and Water Management Plans

The Reference, Less Aggressive, and More Aggressive remedies for soil and groundwater are consistent with general land use plans and water management plans. As summarized in the RO Report, the property with SRL exceedances is currently and will for the foreseeable future be zoned for non-residential use, and the land management plan for LHC indicated land use near to Lake Havasu Avenue and Highway 95 is expected to remain industrial, while properties to the west may be converted to resort-related properties and open space or parks along the Lake Havasu shorelines. Each of the three remedies described herein is consistent with this land use plan.

The RO Report also summarized current and reasonably foreseeable groundwater and surface water use with respect to waters of the state that have been or are threatened to be affected by a release of a hazardous Site-related substance. As indicated in the RO Report, no private wells or small water systems were found in the vicinity of the Site; however, LHC owns six production wells located downgradient of the Site, and there is potential for two additional production wells to be constructed in the future. Each of the three remedies described herein is consistent with this groundwater use, as each will protect against the loss or impairment of potable water threatened by Site COCs by restoring, replacing, or otherwise providing for potable water that is lost or impaired by Site COCs.

Surface water use within the RO Report's study area included recreational activities at Lake Havasu. Surface water from Lake Havasu in the vicinity of the Site is not provided as drinking water, although groundwater at the Site is likely hydraulically connected to the Lake Havasu/Colorado River system. However, a pathway of Site COCs to surface water is considered incomplete as Site COCs do not appear to have migrated to the lake; therefore, the surface water use is not currently threatened by Site COCs. Each of the three remedies described herein is consistent with this surface water use, as each will provide protection for groundwater, as described above.

6.3 Comparison Criteria

The following section compares the Reference Remedy and alternative remedies to the comparison criteria described in A.A.C. R18-16-407H.3, namely practicability, risks, costs, and benefits (Table 2).

Practicability includes the assessment of feasibility, short- and long-term effectiveness, and the reliability of the remedial alternative. The risk criteria include assessment of the overall protectiveness of public health and the environment in terms of fate and transport of the COCs, current and future land and water uses, exposure pathways and durations of potential exposure, changes in risk during remediation, and residual risk at the end of remediation. The cost analysis includes capital, O&M, and life cycle costs. Evaluation of benefits includes the assessment of lowered risk, reduced COC concentration or volume, decrease in liability, and preservation of existing and future uses.

For cost analyses, the estimates are conceptual and assumed to have similar margins of error between +30% and –30% (i.e., the actual costs are expected to be between 30% more than and 30% less than the estimated costs).

6.3.1 Reference Remedy

6.3.1.1 Practicability

The soil and groundwater remedial measures for the Reference Remedy involve technologies that are known and proven reliable remediation technologies. For the soil Reference Remedy, VOC impacts in the vadose zone can be effectively remediated by the SVE system over the term of its three-year operation period, and potential vapor intrusion exposure risk will be quickly mitigated once the system is implemented. Reported VOC impacts to the vadose zone are localized to one area, and SVE is considered practicable for this location.

For the groundwater Reference Remedy, a GETS in conjunction with MNA are well-established technologies that can be highly effective in the short- and long-term. The installation of the GETS would require space and long-term access for monitoring and maintenance. Several options for this location are potentially available near the area of the planned GETS wells.

Because the GETS will not directly address residual COC mass in the vadose zone soil directly above the saturated interface, which may act as a source of COCs to groundwater, it is likely that this remedy will require 30 years or more of continuous operation to meet remedial objectives.

6.3.1.2 Protectiveness (Risk)

The soil Reference Remedy is highly protective, as it will provide source control through removal of VOC mass in the vadose zone. The soil Reference Remedy also mitigates the potential vapor intrusion exposure pathway and is consistent with current and anticipated future industrial land use.

The groundwater Reference Remedy is protective, as the GETS will bisect the plumes and extract and treat contaminated groundwater, reducing COC mass in the plumes and preventing further downgradient migration of COCs from the source area. Additionally, dilute groundwater impacts will be mitigated by MNA in the limited portions of the plumes that may be at the plume peripheries or downgradient of the GETS at time of implementation. Reference Remedy also provides groundwater monitoring of peripheral portions of the plumes not addressed by the GETS and is protective in that it provides continued monitoring of the contaminant plumes and the nearby LHC production wells, with the contingency of ISB if needed to achieve groundwater ROs.

6.3.1.3 Cost

The cost summary for the Reference Remedy is presented in Table 2, and itemized costs are presented in Appendix A. The Reference Remedy cost estimates include O&M and monitoring of the SVE system in the source area vadose zone, and installation, O&M and monitoring of a GETS. It was assumed for costing that the SVE system will include installation of six SVE wells, twelve dual-nested soil vapor probes, and a trailer-mounted blower system and vapor-phase granular activated carbon vessels. The SVE costs assume up to four years of runtime.

For costing of the GETS, it was assumed the two groundwater extraction wells will be installed and piped to a water treatment system designed for a maximum influent rate of 200 gpm. The GETS will include a slab-on-grade foundation and chain-link perimeter fencing for security purposes. The water treatment system includes multi-media filtration, LGAC vessels, and ion-exchange resin technology. It was assumed that the GETS would be operated, maintained and monitored for a period of up to 30 years.

For MNA, it was assumed that the existing monitoring well network, comprised of 40 groundwater wells, will be used for semiannual groundwater monitoring for a period of 30 years, or five years greater than the operation period for the GETS. For costing purposes, it was assumed that monitoring would be required for a 30-year period.

The estimated capital costs for the soil remedy are approximately $0.5 million and approximately $2.9 million in capital costs for GETS installation (excluding contingencies). Total estimated O&M costs (excluding contingencies) are approximately $33.8 million (with an assumed 3% annual inflation), based on the estimation that SVE O&M will be conducted for four years, GETS O&M will be conducted for up to 30 years, and groundwater monitoring activities will be conducted for up to 30 years. The total Reference Remedy costs (with no contingencies) are estimated at approximately $37 million.

Total estimated contingency costs are approximately $10.1 million based on the assumptions included in Appendix A. Contingency costs conservatively assume: ISB will be implemented at the source area for two years; and five-years of additional GETS operation and semiannual groundwater monitoring. The total cost for the Reference Remedy including contingencies is approximately $47.4 million, with a margin of error between $33.2 million (-30%) and $61.6 million (+30%).

6.3.1.4 Benefit

Operation of the SVE system in the Reference Remedy will remove VOC mass in the vadose zone soil and will mitigate the potential for residual VOCs to pose a vapor intrusion risk to building occupants.

The groundwater Reference Remedy will provide treatment of the COC plumes, control the migration of contaminants, and utilize monitoring as a means for evaluating the effectiveness of remediation.

6.3.2 More Aggressive Remedy

6.3.2.1 Practicability

The SVE component of the soil remedial measures for the More Aggressive Remedy is the same as for the Reference Remedy. The SVE system is implementable, highly practicable, and SVE is an effective and reliable remedy for remediation of VOC impacts in the vadose zone.

For the groundwater More Aggressive Remedy, ISB and MNA are well-established technologies that can be highly effective in the short-term (once reducing conditions are established by ISB injections) and over the long-term, as COC concentrations are reduced through ISB- and MNA-related processes. Results from the Site indicate ISB can be highly effective in reducing the concentrations of all groundwater COCs, and have demonstrated that ISB is practicable and implementable under Site conditions.

As with the GETS, several locations for siting ISB infrastructure exist in the area, including right-of-way, private or city-owned property. Because the system would be designed to pump donor solution from a centralized ISB system compound to the ISB injection wells, street closures in a high-traffic urban setting will likely be necessary for trenching of the conveyance system. Both private and public utilities and infrastructure would need to be avoided during installation of the ISB injection wells and the associated conveyance piping.

6.3.2.2 Protectiveness (Risk)

The soil More Aggressive Remedy is highly protective, as SVE will provide source control through removal of VOC mass in the vadose zone, mitigates the potential vapor intrusion exposure pathway and is consistent with current and anticipated future industrial land use.

The groundwater More Aggressive Remedy is highly protective because it will directly treat contaminated groundwater via ISB, resulting in rapid reductions in COC concentrations in the plumes and preventing further downgradient migration of COCs from the source area. Additionally, because ISB near the source area will be performed in a manner designed to induce mounding in the injection area, this remedy will also reduce COC concentrations in vadose zone soil directly above the saturated interface, thus decreasing the likelihood that impacted vadose zone soil will be a source of contamination to groundwater, which will likely reduce the time required to achieve groundwater ROs. Due to the direct treatment of the contamination in the groundwater, the risks are reduced as compared with GETS and/or MNA over the project lifecycle. There is the potential for fouling or difficulty injecting the targeted volume of electron donor solution into the injection wells over the extended operational time period. However, this is considered to be a manageable risk.

Dilute groundwater impacts will be mitigated by MNA in the limited portions of the plumes at the plume periphery or downgradient of the ISB system's zone of influence. The groundwater More Aggressive Remedy also provides groundwater monitoring of peripheral portions of the plumes not directly addressed by the ISB system, and is protective in that it provides continued monitoring of the contaminant plume extents and the nearby LHC production wells, with the contingency of wellhead treatment for the LHC wells if necessary.

6.3.2.3 Cost

The cost summary of the More Aggressive Remedy is presented in Table 2, and itemized costs are presented in Appendix A. The More Aggressive Remedy costs include installation and four years of O&M and monitoring for the SVE system, installation and O&M of the ISB system over a planned four-year ISB injection program, and nine years of semi-annual groundwater monitoring. The costing of the SVE system used the same assumptions as for the Reference Remedy.

The estimated capital costs for the soil remedy are $0.5 million. Approximately $1.2 million are estimated for the ISB system installation (excluding contingencies). Total estimated O&M costs (excluding contingencies) are approximately $5.3 million (with an assumed 3% annual inflation), based on the estimation that SVE O&M will be conducted for four years, the ISB injection O&M program will be conducted for up to four years, and groundwater monitoring activities will be conducted for up to nine years. The total estimated cost for the More Aggressive Remedy without contingencies is $7.0 million.

Total estimated contingency costs are approximately $8.8 million based on the assumptions included in Appendix A. Contingency costs assume: installation of a wellhead treatment for up to two of the LHC wells with a planned 10-year operation period. The total cost for the More Aggressive Remedy including contingency is approximately $15.8 million, with a margin of error between $11.1 million (-30%) and $20.5 million (+30%).

6.3.2.4 Benefit

Operation of the SVE system in the More Aggressive Remedy will remove VOC mass in the vadose zone soil, will mitigate the potential for residual VOCs to pose a vapor intrusion risk to building occupants, and will reduce the time to complete remediation.

The groundwater More Aggressive Remedy will provide rapid treatment of the COC plumes, reducing COC mass and shortening the duration of time to achieve groundwater ROs. Mounding ISB will also remediate COC impacts to vadose zone soils directly above the saturated interface at the source area, which may otherwise act as a source of contaminants to groundwater. Additionally, this remedy utilizes monitoring as a means for evaluating the effectiveness of remediation.

6.3.3 Less Aggressive Remedy

The practicability, risk, cost, and benefit of the Less Aggressive Remedy for the plume are discussed in the following subsections.

6.3.3.1 Practicability

The SVE component of the soil remedial measures for the Less Aggressive Remedy are the same as for the Reference Remedy. The SVE system is implementable, highly practicable, and SVE is an effective and reliable remedy for remediation of VOC impacts in the vadose zone.

The Less Aggressive Remedy for groundwater consists of MNA, a well-established remedial measure that can provide effective long-term remediation of the COC plumes. MNA does not provide short-term effectiveness, but this remedy includes ISB implementation and installation of wellhead treatment for LHC production wells as a contingency if it is determined that COCs in exceedance of AWQS have been detected in the LHC point of compliance monitoring wells, or if it is anticipated that an excessive period of time will be required before groundwater ROs are achieved. While this remedy is considered to be practicable and implementable, with low short-term capital costs, the capital costs associated with the contingency measures must be considered; in particular, installation of a wellhead treatment system at the LHC production wells would require capital outlays.

6.3.3.2 Protectiveness (Risk)

The soil Less Aggressive Remedy is protective, as the remedy removes VOC mass from the vadose zone soil, reduces the potential vapor intrusion exposure risk, and is consistent with current and anticipated future industrial land use.

The Less Aggressive Remedy for groundwater is protective because it mitigates the potential for exposure via the groundwater consumption pathway (i.e., ingestion, inhalation, or dermal contact) by monitoring the potential migration of COC plumes towards the LHC production wells, where an exposure pathway could be completed. This remedy includes the contingency of installing wellhead treatment for LHC production wells, should it be necessary, thereby mitigating the groundwater consumption potential exposure pathway.

6.3.3.3 Cost

The cost summary for the Less Aggressive Remedy is presented in Table 2, and itemized costs are presented in Appendix A. The Less Aggressive Remedy cost estimates includes O&M and monitoring of the SVE system in the source area vadose zone soil, installation of additional monitoring wells, and 30 years of MNA. The costing assumptions for the SVE system were the same as for the Reference Remedy.

The estimated capital costs for the soil remedy are $0.5 million (excluding contingencies), and the capital costs for installing two additional monitoring wells is approximately $0.2 million. Total estimated O&M costs (excluding contingencies) are approximately $9.5 million (with an assumed 3% annual inflation), based on the estimation that SVE O&M will be conducted for four years, and MNA groundwater monitoring activities will be conducted for up to 30 years. Therefore, the total estimated costs for the Less Aggressive Remedy without contingencies is $10.2 million.

Total estimated contingency costs are approximately $15.0 million based on the assumptions included in Appendix A. Contingency costs conservatively assume: installation of wellhead treatment for up to two of the LHC wells with a planned 30-year O&M period, and two-years of ISB implementation. The total cost for the Less Aggressive Remedy including contingency is approximately $25.1 million, with a margin of error between $17.6 million (-30%) and $32.6 million (+30%).

6.3.3.4 Benefit

Operation of the SVE system in the Less Aggressive Remedy will remove VOC mass in the vadose zone soil, will mitigate the potential for residual VOCs to pose a vapor intrusion risk to building occupants, and will reduce the time to complete remediation.

The groundwater Less Aggressive Remedy provides treatment of the COC plumes through MNA-related attenuation processes, reducing COC mass over the longer-term. The remedy also provides monitoring of the COC plumes as a means for evaluating the effectiveness of remediation, and as a means for assessing the potential migration of COC plumes towards the LHC production wells. Additionally, MNA of groundwater would not affect neighboring properties with the installation of the extraction or injection well networks and related infrastructure proposed in the Reference Remedy and the More Aggressive Alternate Remedy. However, the downgradient plume would likely persist for a very long period of time, and may impact downgradient LHC production wells, potentially triggering a high-cost contingency.

6.4 Comparison of Remedies

Comparison of the remedies is required under the A.A.C. R18 16-407(H). Table 2 presents the comparison criteria for each of the remedies. The following sections describe the practicability, risk, cost, and benefits comparison for remedies.

6.4.1 Practicability

There are several considerations for practicability, including:

- Feasibility of putting the remedy in place;
- Long- and short-term effectiveness of the remedy; and
- Reliability of the remedy.

Soil Remedies

For the vadose zone soil, the three remedies propose to include the same SVE system. This technology is considered to be technically and operationally feasible, with both long- and short-term effectiveness, and is a reliable technology. The More Aggressive Remedy is the only alternative that will provide remediation of vadose zone soil impacts directly above the saturated interface, potentially increasing the long-term effectiveness of this remedy.

Groundwater Remedies

For groundwater, all three remedies are feasible. The More Aggressive Remedy and the Reference Remedy are both similarly effective in the short-term, but the Reference Remedy has lower long-term effectiveness and reliability, owing to the likely extended period of operation time required for the GETS to achieve groundwater ROs. The Less Aggressive Remedy has significantly lower short- and long-term effectiveness than the other remedies, as MNA relies entirely on natural processes to reduce contaminant mass from the groundwater and will require an extended period of time to meet groundwater ROs.

6.4.2 Protectiveness (Risk)

The soil remedies are protective of risk, since the three remedies will remove VOC mass from the vadose zone soil, reduce the potential vapor intrusion exposure risk, and are consistent with current and anticipated future industrial land use. The More Aggressive Remedy decreases the possible future risk of additional contaminants mobilizing from the lower vadose zone soil should groundwater levels increase above current levels.

The groundwater More Aggressive Remedy is more protective than the Reference Remedy primarily due to the anticipated shorter period of operation time; ISB is expected to achieve groundwater ROs significantly faster than the GETS, the latter which will likely require decades to achieve ROs, with risk of operational upset over the anticipated long-term operation timeframe.

The groundwater Less Aggressive Remedy has the lowest protectiveness since it involves no active groundwater remediation; however, all proposed remedies include contingencies to mitigate potential risks to groundwater resources in the vicinity of the Site. In addition, there is a high probability that contingency measures (ISB and/or wellhead treatment for the LHC production wells) will be necessary.

6.4.3 Cost

The three remedies have varying capital and O&M costs. Including capital and O&M costs (not including contingencies), it is estimated that:

- The Reference Remedy is estimated to cost $37.3 million;
- The More Aggressive Remedy is estimated to cost $7.0 million; and
- The Less Aggressive Remedy is estimated to cost $10.2 million.

The contingency costs for each remedy are estimated to be:

- The Reference Remedy is estimated to cost $10.1 million;
- The More Aggressive Remedy is estimated to cost $8.8 million; and
- The Less Aggressive is estimated to cost $15.0 million.

The More Aggressive Remedy has the lowest cost excluding contingencies, making it the likely most cost-effective of the remedies. The Reference and the More Aggressive Remedy have lower risks of triggering contingency costs.

6.4.4 Benefit

The Reference Remedy and the Less Aggressive Remedy soil remedies are equally beneficial, since they will remove VOC mass from the vadose zone soil, reduce the potential vapor intrusion exposure risk, and are consistent with current and anticipated future industrial land use. The More Aggressive Remedy also has these benefits, with an additional benefit of treatment of source area vadose zone soils directly above the saturated interface, which will reduce the potential for these soils to act as a source of COCs to groundwater.

The groundwater Reference Remedy and More Aggressive Remedy had similar benefits since they both include active groundwater remediation systems. However, the More Aggressive Remedy's ISB is anticipated to reach ROs in a significantly shorter period of time than the Reference Remedy GETS. The More Aggressive Remedy's ISB is also the only remedy that will target source area groundwater.

7. RECOMMENDED REMEDY

The More Aggressive Remedy is recommended as the proposed remedy at the Site for both soil and groundwater.

The following presents the recommended remedy for both soil and groundwater, as well as the basis for selecting the recommended remedy. Cost information for the remedial alternatives is included in Appendix A.

7.1 Process and Reason for Selection

This remedy selection provides the best combination of remedial effectiveness, practicably, cost, and benefit when evaluating in accordance with the comparison criteria specified in A.A.C R1816-407H.3.e (Section 6).

7.2 Achievement of Remedial Objectives

The More Aggressive Remedy for the soil will provide source control for the vadose zone soil, will remove VOC mass in the vadose zone, will mitigate the potential for residual VOCs to pose a vapor intrusion risk to building occupants, and will reduce the time to complete remediation.

The groundwater More Aggressive Remedy will provide the most rapid treatment of the COC plumes, reducing COC mass and shortening the duration of time to achieve groundwater ROs. Induced mounding during ISB implementation will also mitigate COC impacts to vadose zone soils directly above the saturated interface at the source area, which may otherwise act as a source of contaminants if groundwater levels rise in the future. Additionally, this remedy utilizes monitoring as a means for evaluating the effectiveness of remediation.

7.3 Achievement of Remedial Action Criteria Pursuant to A.R.S. §49-282.06

The More Aggressive Remedy will meet A.R.S. §49-282.06 by:

- Providing for protection of public health and welfare and the environment by removing VOC mass from the vadose zone and directly treating groundwater that is used as a drinking water source;
- Providing source area vadose zone remediation, decreased risk to building occupants, and mitigating further contribution of COCs from the vadose zone source area to groundwater;
- Providing a rapid, thorough and timely means for remediation and monitoring of the existing groundwater impacts, including evaluation of the progress of remediation over time;
- Providing for the control, management, and cleanup of the COCs in groundwater, to the extent practicable;
- Providing for the beneficial use of the groundwater resource by LHC; and
- Being reasonable, cost-effective, and technically feasible.

8. COMMUNITY INVOLVEMENT

ADEQ will issue a Notice to the Public announcing the availability of FS on ADEQ's website at www.azdeq.gov. The notice may be mailed to the Public Mailing List for the Site, water providers, the Community Advisory Board (CAB), and any other interested parties. ADEQ may also present a summary of this FS and the remedial alternatives in a CAB meeting.

Interested parties can also review the FS and other site documents at the ADEQ Main Office located at 1110 West Washington Street, Phoenix, Arizona. With 24-hour notice, an appointment can be made to review related documentation.

9. REFERENCES

ADEQ, 2018, *Public Notice: Notice of Hazardous Substance Listing and Availability Water Quality Assurance Revolving Fund Remedial Investigation and Feasibility Study*, 20 February.

ADEQ, 2019, *Re: No Further Action Determination for Soil, Kiowa Ponds*, 30 August.

Geosyntec and ADEQ, 2020, *Final Remedial Investigation Report, Lake Havasu Avenue and Holly Avenue Water Quality Assurance Revolving Fund Site*, Lake Havasu City, Arizona, 18 December.

URS, 2001, *MW-21 Aquifer Test Final Report*, McCulloch Facility, 10 October.

USEPA, 2018, *Regional Screening Level (RSL) Summary Table (TR=1E-06, HQ=1)*, November. www.epa.gov/risk/regional-screening-levels-rsls-generic-tables.

TABLE

Table 2
Remedy Evaluation
Lake Havasu Avenue and Holly Avenue WQARF Site
Lake Havasu City, Arizona

Remedial Alternative	Vadose Zone / Groundwater	Will Alternative Meet Remedial Objectives?	Practicability	Protectiveness (Risk)	Costs	Benefits	Regulatory/Public Acceptance
Reference Remedy	**Source Area SVE, Paving Maintenance**	Yes, SVE will reduce VOC concentrations and decrease risks of VI. The maintenance of paving will prevent exposure to Cr contamination	SVE is a known feasible remedial technology, is very implementable, and likely effective	SVE is very protective, as it removes VOCs from vadose zone and mitigates exposure pathways. Maintenance of the paving prevents against exposure to Cr soils.	Remedy Cost: $37.3 million ($26.1 million to $48.5 million [+/-30%]) Contingency Cost: $10.1 million ($7.1 million to $13.1 million [+/-30%])	Will remove VOC mass in the vadose zone and will mitigate the potential for residual VOCs to pose a vapor intrusion risk to building occupants.	Highly Likely
	GETS, MNA	Yes, GETS will capturie all COCs in the plumes, preventing further migration of COCs towards LHC wells	GETS is a known feasible remediation measure, is moderatly implementable as siting of the treatment system would have potential challenges, and likely effective.	GETS is very protective as it will capture the plumes and treat contaminated groundwater, reducing COC mass and preventing further downgradient migration. MNA will ensure residual contamination does not reach the LHC wells.		Provides treatment of the COC plumes and controls the migration of contaminants, and monitors concentrations throughout the plumes.	Likely
More Aggressive Remedy	**Source Area SVE and ISB, Paving Maintenance**	Yes, SVE will reduce VOC concentrations and decrease risks of VI, the ISB will reduce the amount of soil contamination, and the maintenance of paving will prevent exposure	SVE is a known feasible remedial technology, is very implementable, and likely effective. ISB injections in the vadose zone is likely feasible, moderately implementable, and likely effective.	The More Aggresive Remedy is protective, as it removes VOCs from vadose zone, mitigates exposure pathways and is consistent with current and future land use.	Remedy Cost: $7.0 million ($4.9 million to $9.1 million [+/-30%]) Contingency Cost: $8.8 million ($6.2 million to $11.5 million [+/- 30%])	Will remove VOC mass in the vadose zone and will mitigate the potential for residual VOCs to pose a vapor intrusion risk to building occupants.	Highly Likely
	ISB, MNA and Semiannual Monitoring of Existing Groundwater Well Network	Yes, ISB will reduce COC concentratins and prevent further migration of COCs from the source area and the highest concentration areas of the plumes. MNA will monitor as natural attenuation decreases COCs in the diffuse plume areas.	ISB is very feasible, is highly implementable as siting of the treatment system would be on right-of-way and properties with known access availbility, and likely effective.	The ISB is very protective, as it will directly treat contaminated groundwater resulting in rapid reductions in COC concentrations in the plumes and preventing further downgradient migration of COCs from the source area. It will likely reduce the time required to achieve groundwater ROs. The remedy also provides for MNA of the diffuse portions of the plumes which provides continued monitoring to ensure the plumes are not moving towards the LHC production wells.		Provide rapid treatment of the COC plumes, reducing COC mass and shortening the duration of time to achieve groundwater ROs, and monitors concentrations throughout the plumes.	Highly Likely
Less Aggressive Remedy	**Source Area SVE, Paving Maintenance**	Yes, SVE will reduce VOC concentrations and decrease risks of VI. The maintenance of paving will prevent exposure to Cr contamination	SVE is a known feasible remedial technology, is very implimentable, and likely effective	SVE is very protective, as it removes VOCs from vadose zone and mitigates exposure pathways. Maintenance of the paving prevents against exposure to Cr soils.	Remedy Cost: $10.2 million ($7.1 million to $13.2 million [+/- 30%]) Contingency Cost: $15.0 million ($10.5 million to $19.5 million [+/- 30%])	Will remove VOC mass in the vadose zone and will mitigate the potential for residual VOCs to pose a vapor intrusion risk to building occupants.	Highly Likely
	MNA	Yes, groundwater ROs will likely be achieved through MNA-related attenuation processes. Remedy will provide data for continued evaluation of the plumes.	MNA is feasible, highly implementable, and likely effective. The time-frame for this effectiveness may be long.	Mitigates the potential for exposure via the groundwater by monitoring the potential migration of COC plumes towards the LHC production wells. It is highly likely to trigger the contingency of wellhead treatment to maintain protectiveness.		Provides treatment of the COC plumes through MNA-related attenuation processes, reducing COC mass over the longer-term. and monitoring the COC plumes to evaluate the potential migration of COC plumes towards the LHC production wells.	Less Likely

Abbreviations:
ISB - In situ Bioremediation
MNA - Monitored Natural Attenuation
RO = Remedial Objective
LHC = Lake Havasu City
COC - Constituent of Concern
SVE - Soil Vapor Extraction
GETS = Groundwater Extraction and Treatment System
VOC - Volatile Organic Compound

FIGURES

2,000 1,000 0 2,000 Feet

Site Location

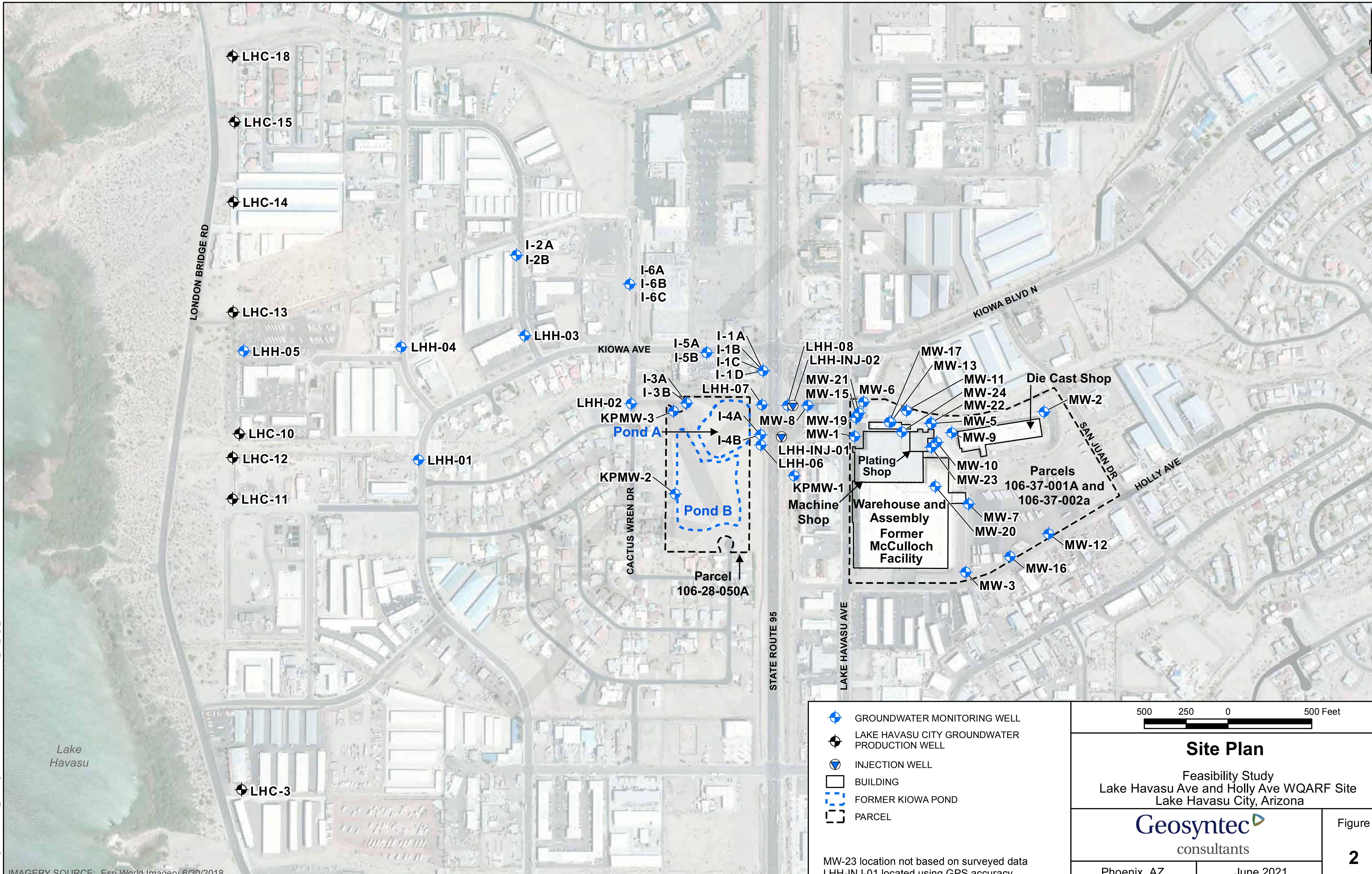
Feasibility Study
Lake Havasu Ave and Holly Ave WQARF Site
Lake Havasu City, Arizona

Geosyntec consultants

Figure 1

Phoenix, AZ | June 2021

\\SanDiego-01\Data\GIS_SanDiego01\SP0164\MXD\GWM\2020\Havasu_TM_Fig1_Loc.mxd SWolfskill 11/5/2020



MW-23 location not based on surveyed data
LHH-INJ-01 located using GPS accuracy

Site Plan

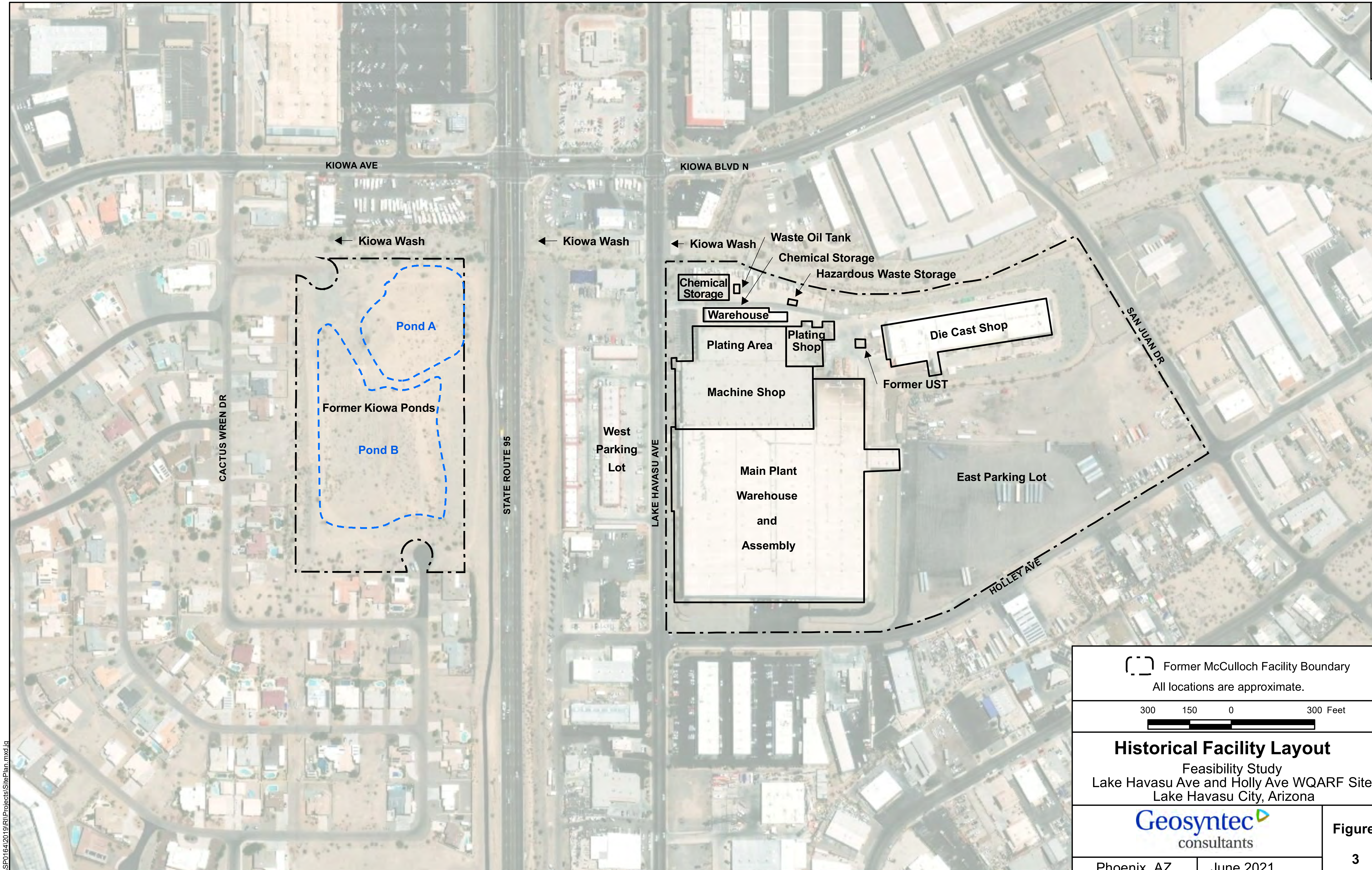
Feasibility Study
Lake Havasu Ave and Holly Ave WQARF Site
Lake Havasu City, Arizona

Geosyntec consultants

Phoenix, AZ | June 2021

Figure 2

\\SanDiego-01\Data\GIS_SanDiego01\SP0164\MXD\GWM\2020\Havasu_TM_Fig2_Site.mxd SWolfskill 11/9/2020



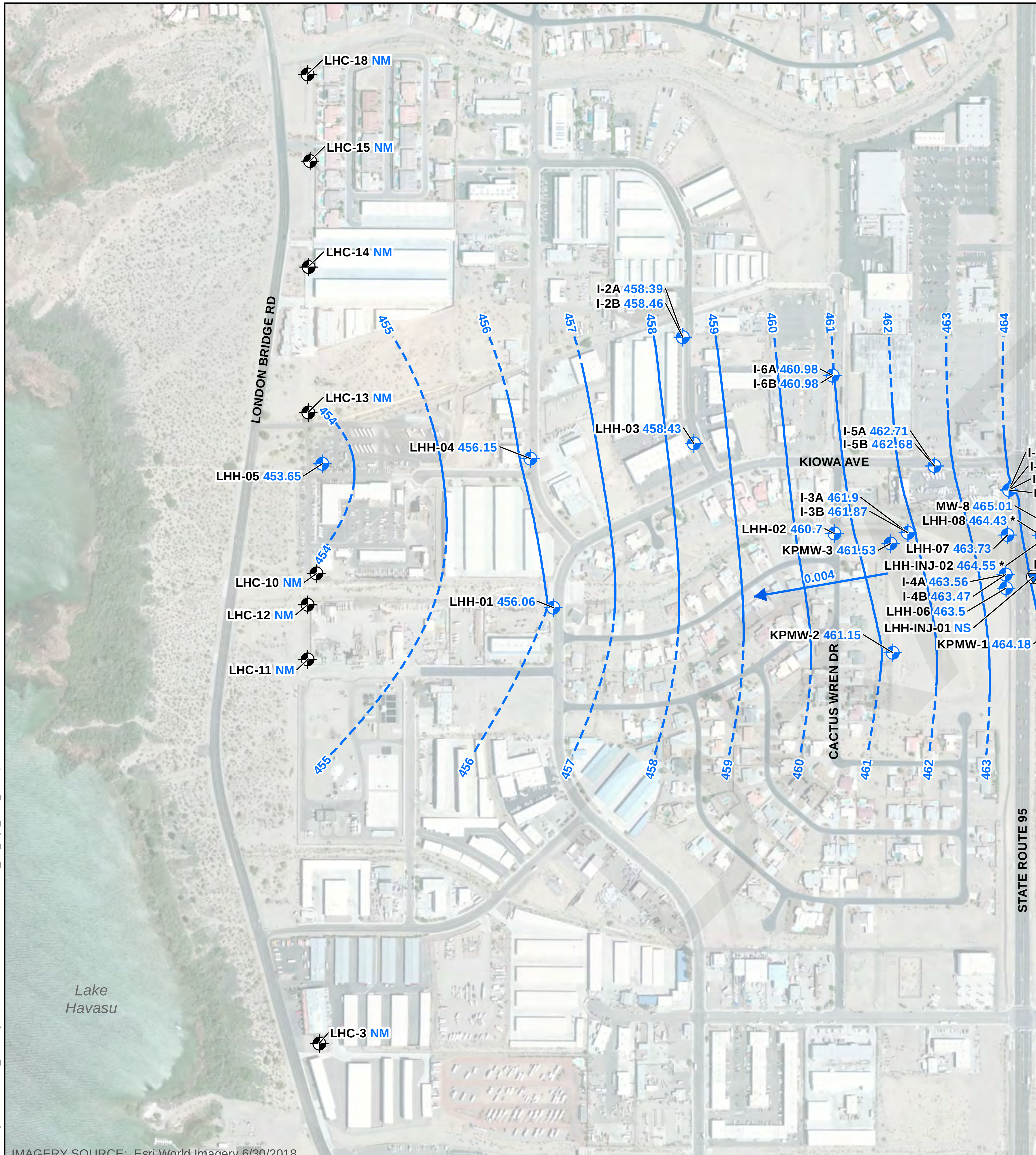
Historical Facility Layout

Feasibility Study
Lake Havasu Ave and Holly Ave WQARF Site
Lake Havasu City, Arizona

Geosyntec consultants

Phoenix, AZ | June 2021

Figure 3



GROUNDWATER MONITORING WELL
CITY OF TUCSON GROUNDWATER PRODUCTION WELL
INJECTION WELL
GROUNDWATER ELEVATION CONTOUR
GROUNDWATER ELEVATION CONTOUR - INFERRED
APPROXIMATE DIRECTION OF GROUNDWATER FLOW

NS = Not Sampled
* = Measurement not used for contouring
- Groundwater measurements used for contouring were collected between September 2 and September 14, 2020
- LHH-INJ-01 located using GPS accuracy

500 250 0 500 Feet

Groundwater Elevation Contours September 2020

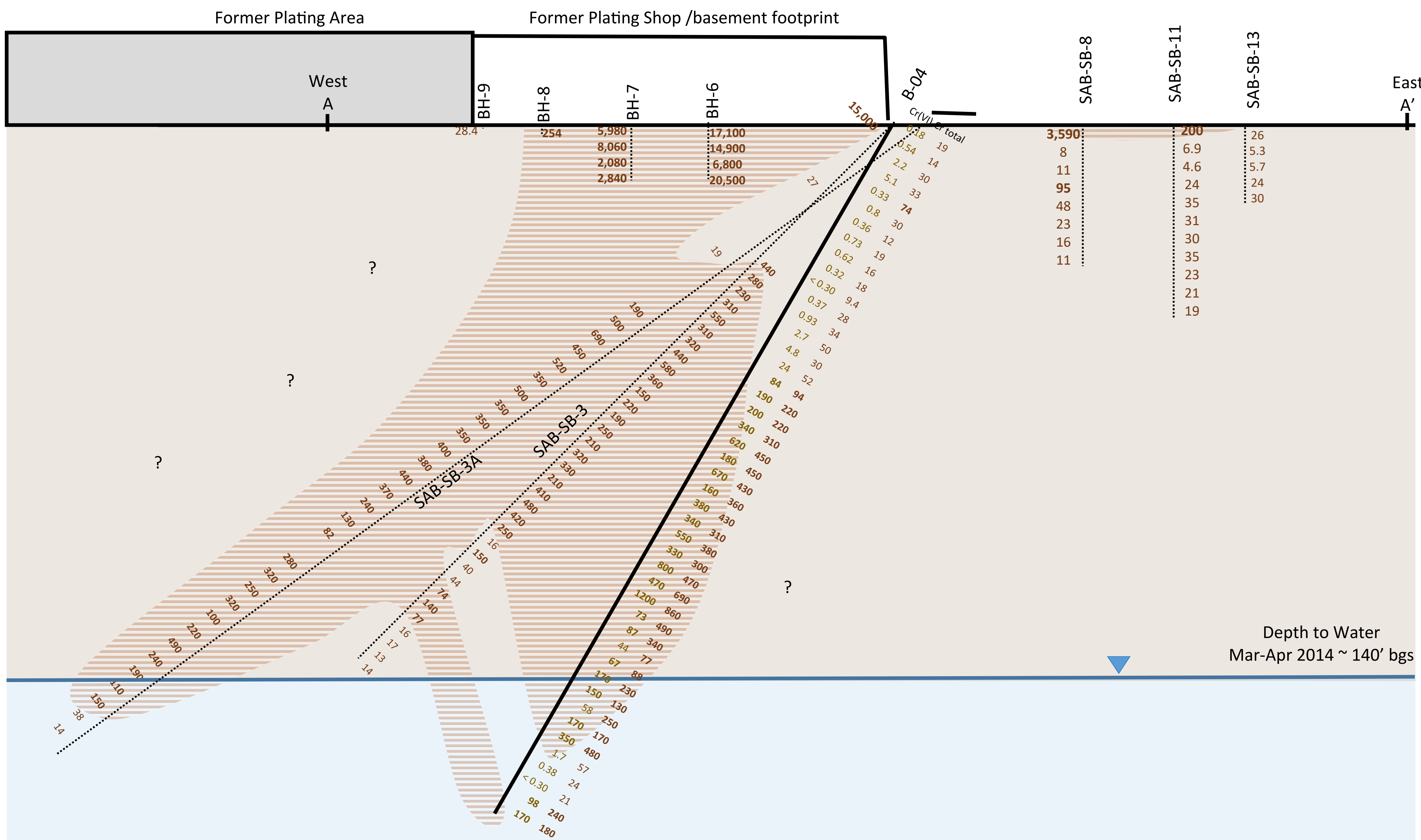
Feasibility Study
Lake Havasu Ave and Holly Ave WQARF Site
Lake Havasu City, Arizona

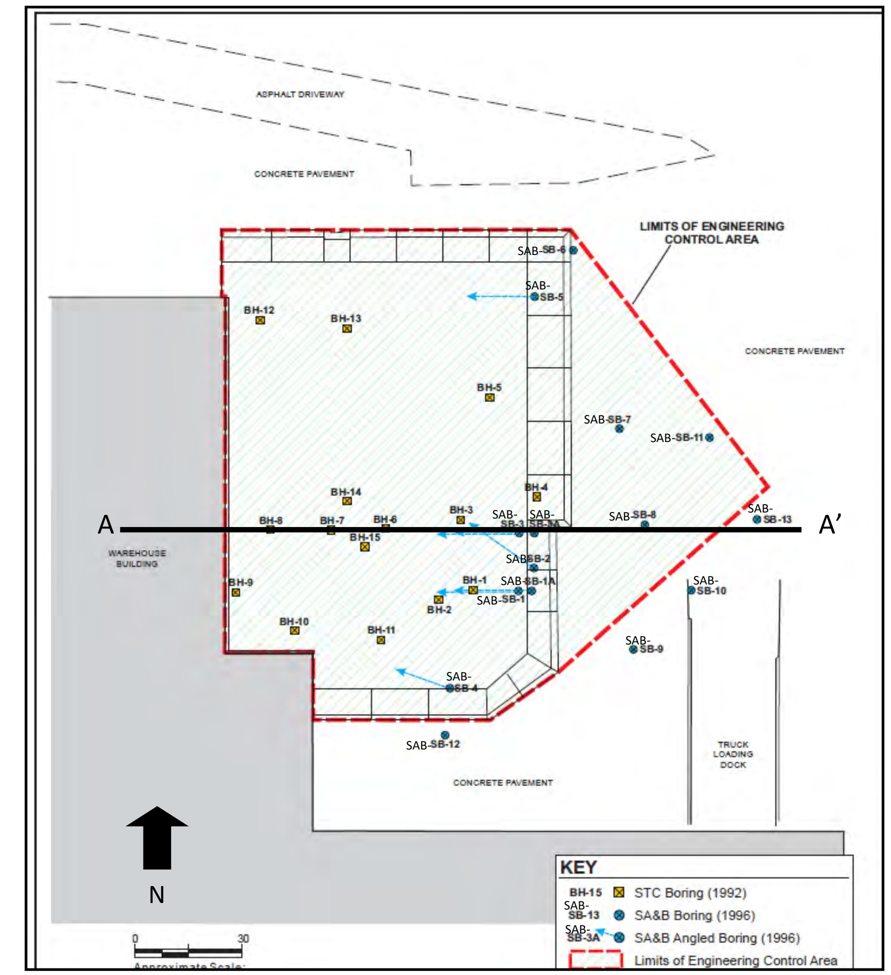
Geosyntec consultants

Phoenix, AZ | June 2021

Figure 4

\\SanDiego-01\Data\GIS_SanDiego01\SP0164\MXD\GWM\2020\Havasu_TM_Fig3_GWL_2020Q3.mxd SWolfskill 11/17/2020





Legend

- Historical borings
- ADEQ boring
- Groundwater level
- 254 Total chromium result in mg/kg
- 250 Hexavalent chromium result in mg/kg
- Approximate area of chromium in soils
- Vadose zone
- Saturated zone

Approximate scale

0 15 30 60 Feet

Historical data from:

N&M, 2014b, *Engineering Control Plan Former McCulloch Facility Plating Shop Area*, 25 July.

Extent of Chromium Contamination in Soils

Feasibility Study

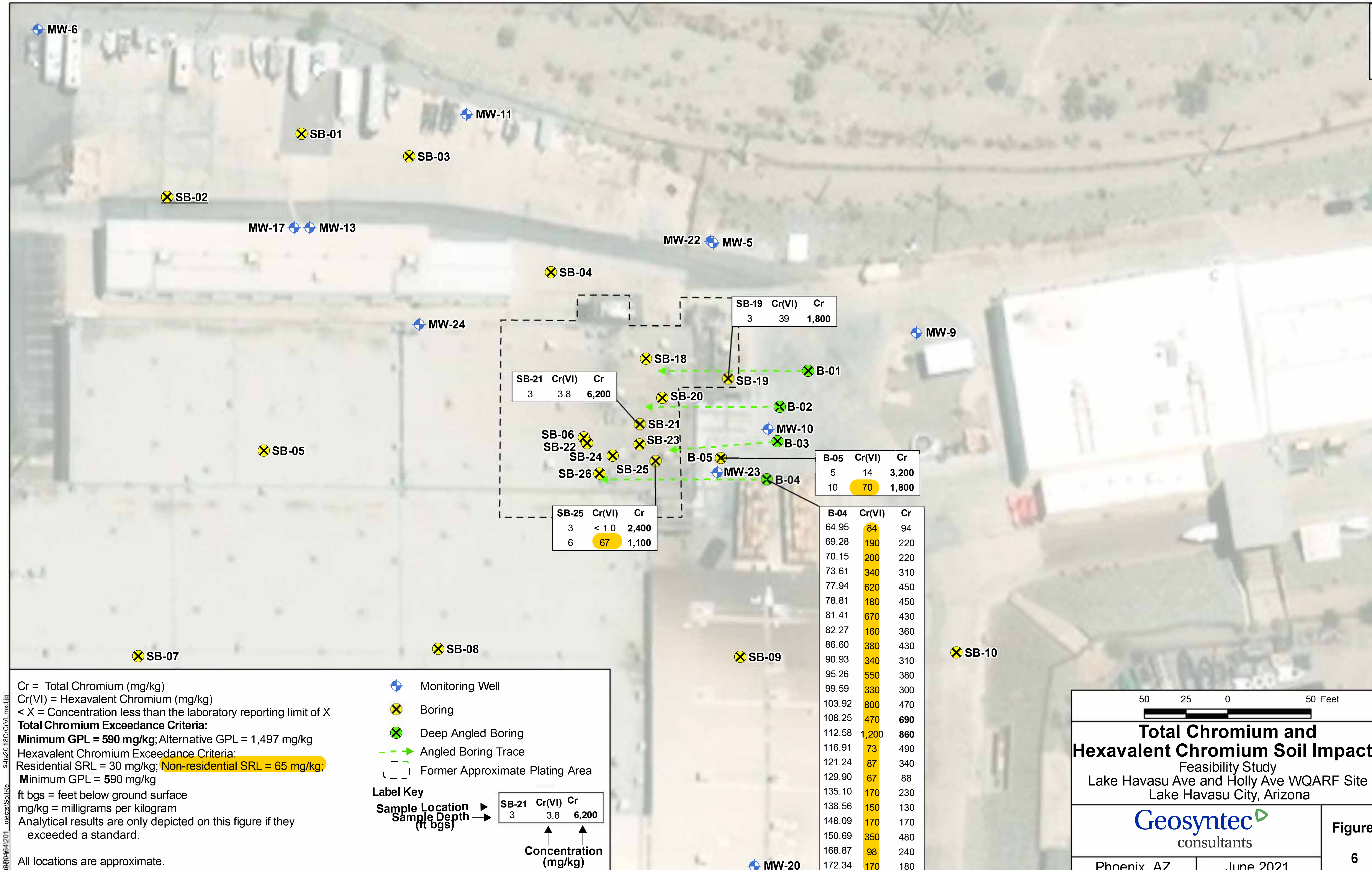
Lake Havasu Ave and Holly Ave WQARF Site

Lake Havasu City, Arizona

ADEQ Arizona Department of Environmental Quality

Phoenix, AZ | June, 2021

Figure 5



SB-19	Cr(VI)	Cr
3	39	1,800

SB-21	Cr(VI)	Cr
3	3.8	6,200

B-05	Cr(VI)	Cr
5	14	3,200
10	70	1,800

SB-25	Cr(VI)	Cr
3	< 1.0	2,400
6	67	1,100

B-04	Cr(VI)	Cr
64.95	84	94
69.28	190	220
70.15	200	220
73.61	340	310
77.94	620	450
78.81	180	450
81.41	670	430
82.27	160	360
86.60	380	430
90.93	340	310
95.26	550	380
99.59	330	300
103.92	800	470
108.25	470	**690**
112.58	1,200	**860**
116.91	73	490
121.24	87	340
129.90	67	88
135.10	170	230
138.56	150	130
148.09	170	170
150.69	350	480
168.87	98	240
172.34	170	180

Cr = Total Chromium (mg/kg)
Cr(VI) = Hexavalent Chromium (mg/kg)
< X = Concentration less than the laboratory reporting limit of X
Total Chromium Exceedance Criteria:
Minimum GPL = 590 mg/kg; Alternative GPL = 1,497 mg/kg
Hexavalent Chromium Exceedance Criteria:
Residential SRL = 30 mg/kg; Non-residential SRL = 65 mg/kg;
Minimum GPL = 590 mg/kg
ft bgs = feet below ground surface
mg/kg = milligrams per kilogram
Analytical results are only depicted on this figure if they exceeded a standard.

All locations are approximate.

Monitoring Well
Boring
Deep Angled Boring
Angled Boring Trace
Former Approximate Plating Area

Label Key

Sample Location →
Sample Depth (ft bgs) →

SB-21	Cr(VI)	Cr
3	3.8	6,200

Concentration (mg/kg)

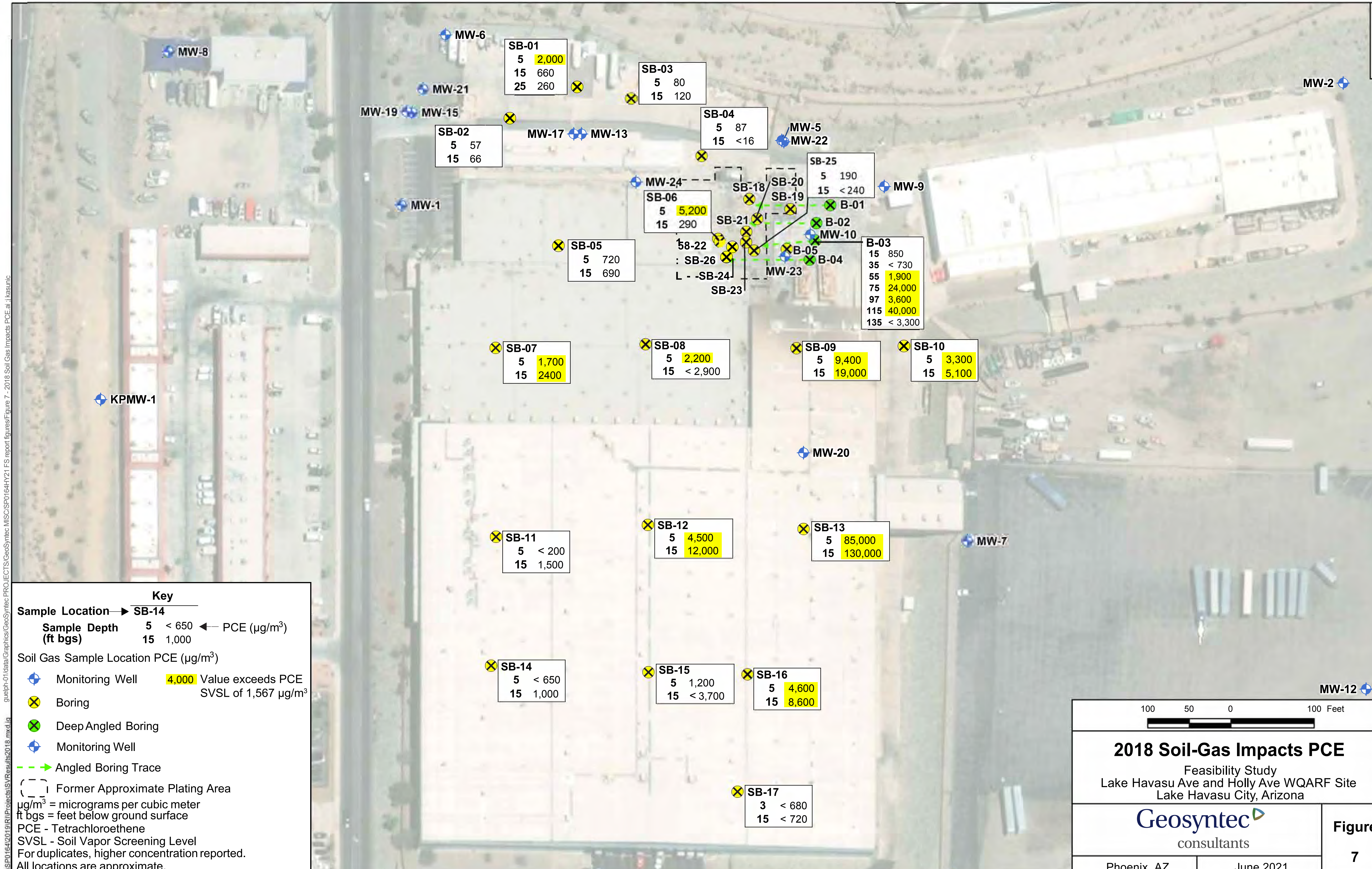
Total Chromium and Hexavalent Chromium Soil Impacts

Feasibility Study
Lake Havasu Ave and Holly Ave WQARF Site
Lake Havasu City, Arizona

Geosyntec consultants

Phoenix, AZ | June 2021

Figure 6



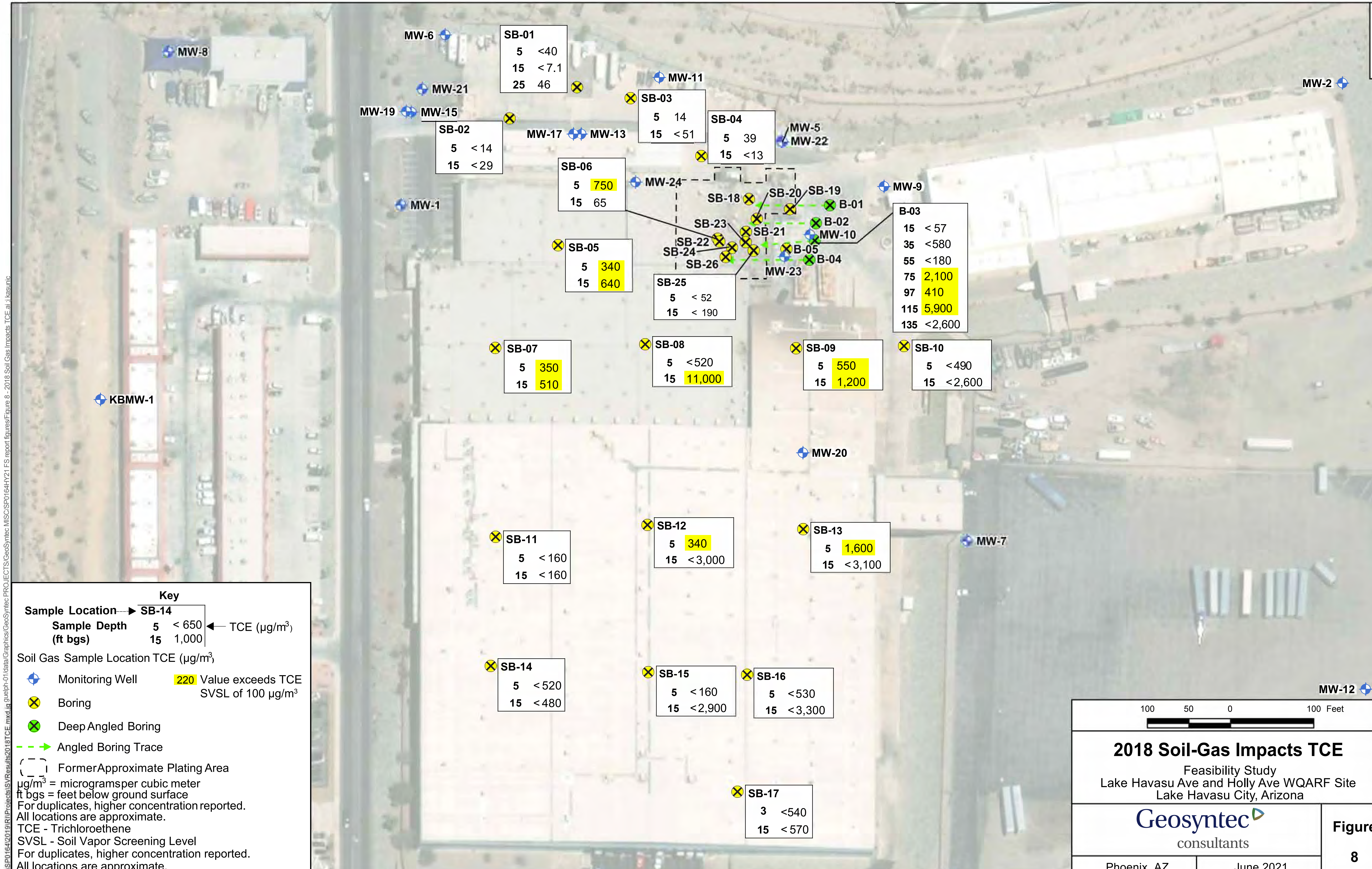
2018 Soil-Gas Impacts PCE

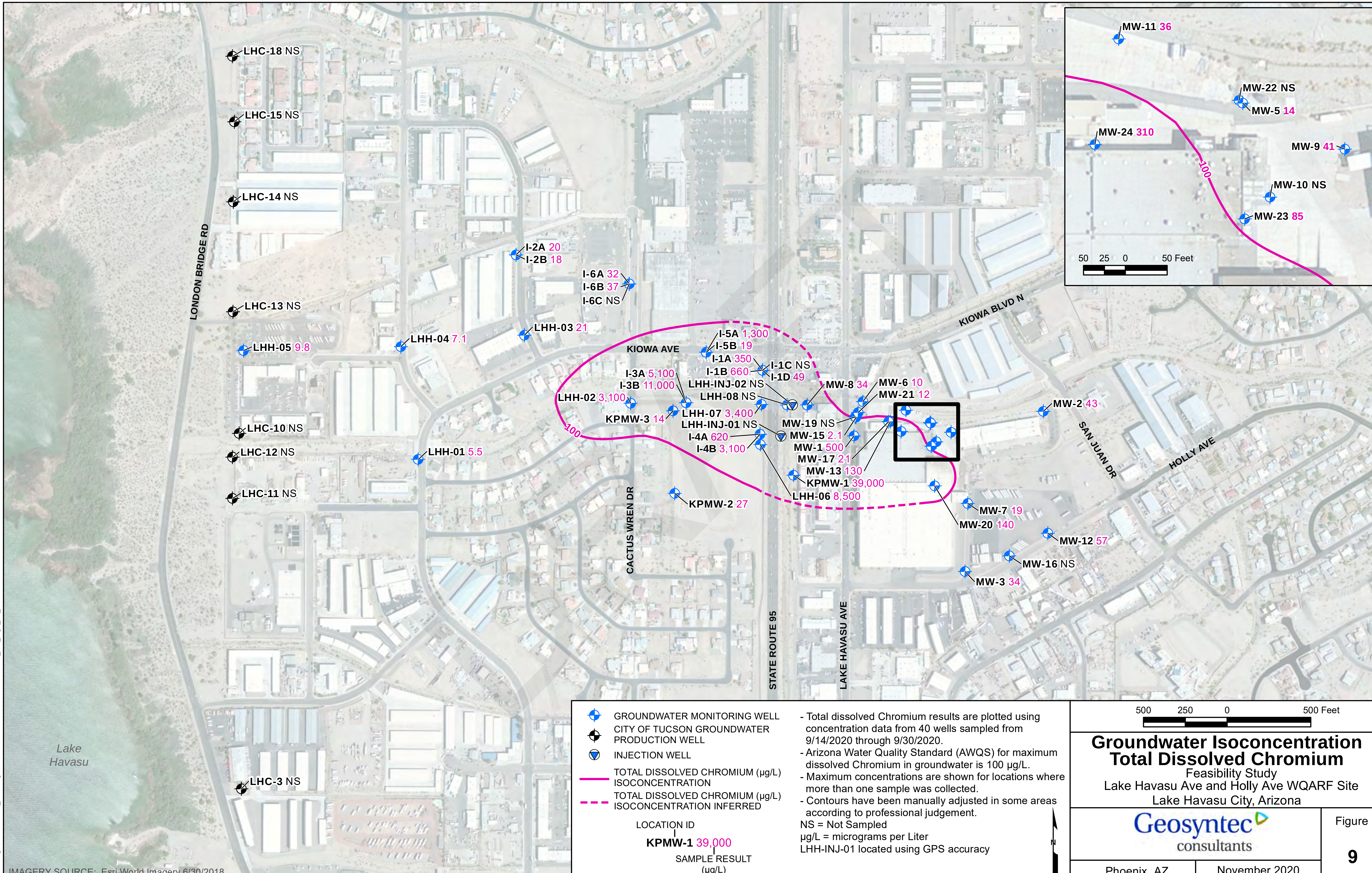
Feasibility Study
Lake Havasu Ave and Holly Ave WQARF Site
Lake Havasu City, Arizona

Geosyntec consultants

Phoenix, AZ | June 2021

Figure 7


MW-8
MW-6
SB-01
5 <40
15 <7.1
25 46
MW-21
MW-11
SB-03
5 14
15 <51
MW-2
MW-19
MW-15
SB-02
5 < 14
15 < 29
MW-17
MW-13
SB-04
5 39
15 <13
MW-5
MW-22
SB-06
5 750
15 65
MW-24
MW-1
SB-18
SB-20
SB-19
B-01
MW-9
B-03
15 < 57
35 <580
55 <180
75 2,100
97 410
115 5,900
135 <2,600
SB-23
SB-21
B-02
MW-10
SB-22
SB-24
SB-26
B-05
B-04
MW-23
SB-05
5 340
15 640
SB-25
5 < 52
15 < 190
SB-07
5 350
15 510
SB-08
5 <520
15 11,000
SB-09
5 550
15 1,200
SB-10
5 <490
15 <2,600
KBMW-1
MW-20
SB-11
5 < 160
15 < 160
SB-12
5 340
15 < 3,000
SB-13
5 1,600
15 < 3,100
MW-7
Key
Sample Location
SB-14
Sample Depth (ft bgs)
5 < 650
15 1,000
TCE (µg/m³)
Soil Gas Sample Location TCE (µg/m³)
Monitoring Well
220 Value exceeds TCE SVSL of 100 µg/m³
Boring
Deep Angled Boring
Angled Boring Trace
FormerApproximate Plating Area
µg/m³ = microgramsper cubic meter
ft bgs = feet below ground surface
For duplicates, higher concentration reported.
All locations are approximate.
TCE - Trichloroethene
SVSL - Soil Vapor Screening Level
For duplicates, higher concentration reported.
All locations are approximate.
SB-14
5 <520
15 <480
SB-15
5 < 160
15 < 2,900
SB-16
5 <530
15 < 3,300
MW-12
SB-17
3 <540
15 < 570
100 50 0 100 Feet
2018 Soil-Gas Impacts TCE
Feasibility Study
Lake Havasu Ave and Holly Ave WQARF Site
Lake Havasu City, Arizona
Geosyntec
consultants
Figure
8
Phoenix, AZ
June 2021



GROUNDWATER MONITORING WELL

CITY OF TUCSON GROUNDWATER PRODUCTION WELL

INJECTION WELL

TOTAL DISSOLVED CHROMIUM (µg/L) ISOCONCENTRATION

TOTAL DISSOLVED CHROMIUM (µg/L) ISOCONCENTRATION INFERRED

LOCATION ID

KPMW-1 39,000

SAMPLE RESULT (µg/L)

- Total dissolved Chromium results are plotted using concentration data from 40 wells sampled from 9/14/2020 through 9/30/2020.
- Arizona Water Quality Standard (AWQS) for maximum dissolved Chromium in groundwater is 100 µg/L.
- Maximum concentrations are shown for locations where more than one sample was collected.
- Contours have been manually adjusted in some areas according to professional judgement.

NS = Not Sampled

µg/L = micrograms per Liter

LHH-INJ-01 located using GPS accuracy

N

500 250 0 500 Feet

Groundwater Isoconcentration Total Dissolved Chromium

Feasibility Study

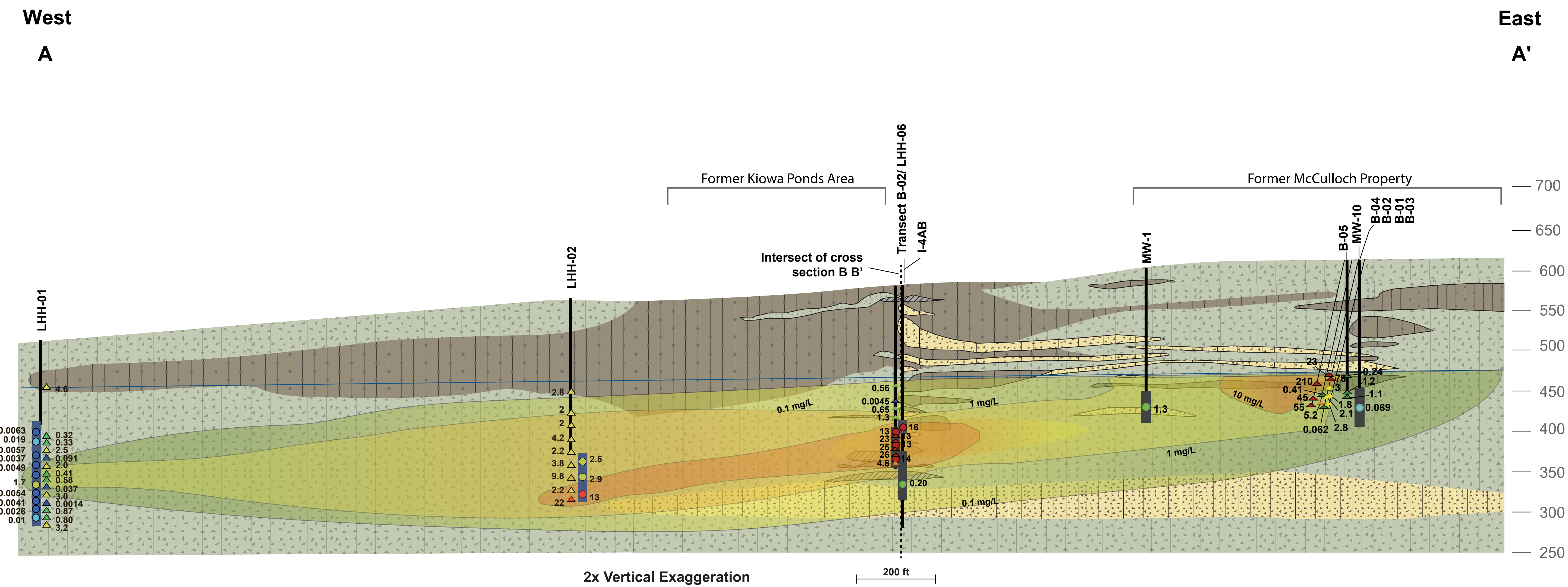
Lake Havasu Ave and Holly Ave WQARF Site

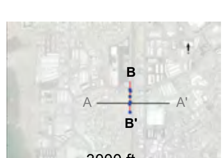
Lake Havasu City, Arizona

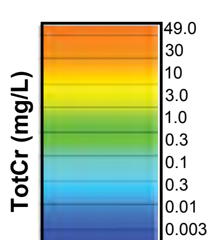
Geosyntec consultants

Figure 9

Phoenix, AZ | November 2020







- Groundwater Surface Concentration Isoline
- Well Screen Interval
- Hydropunch Sample
- Groundwater Sample
- Sandy Lean Clay; Sandy Lean Clay with Gravel
- Well/Poorly Graded Gravel; Well/Poorly Graded Gravel with Sand
- Well/Poorly Graded Sand with Clay; Well/Poorly Graded Sand with Clay and Gravel; Silty Sand; Silty Sand with Gravel; Clayey Sand; Clayey Sand with Gravel
- Well/Poorly Graded Sand; Well/Poorly Graded Sand with Gravel

Notes:
- Total Chromium (TotCr) results are plotted using concentration data from 31 wells and borings sampled from March 2014 through April 2019.
- Samples shown without screens were collected as grab samples from borings not completed as monitoring wells.
- Non-detect results are shown at the laboratory reporting limit.
- mg/L = milligrams per liter
- TotCr plume is shown greater than the AWQS of 0.1 mg/L.

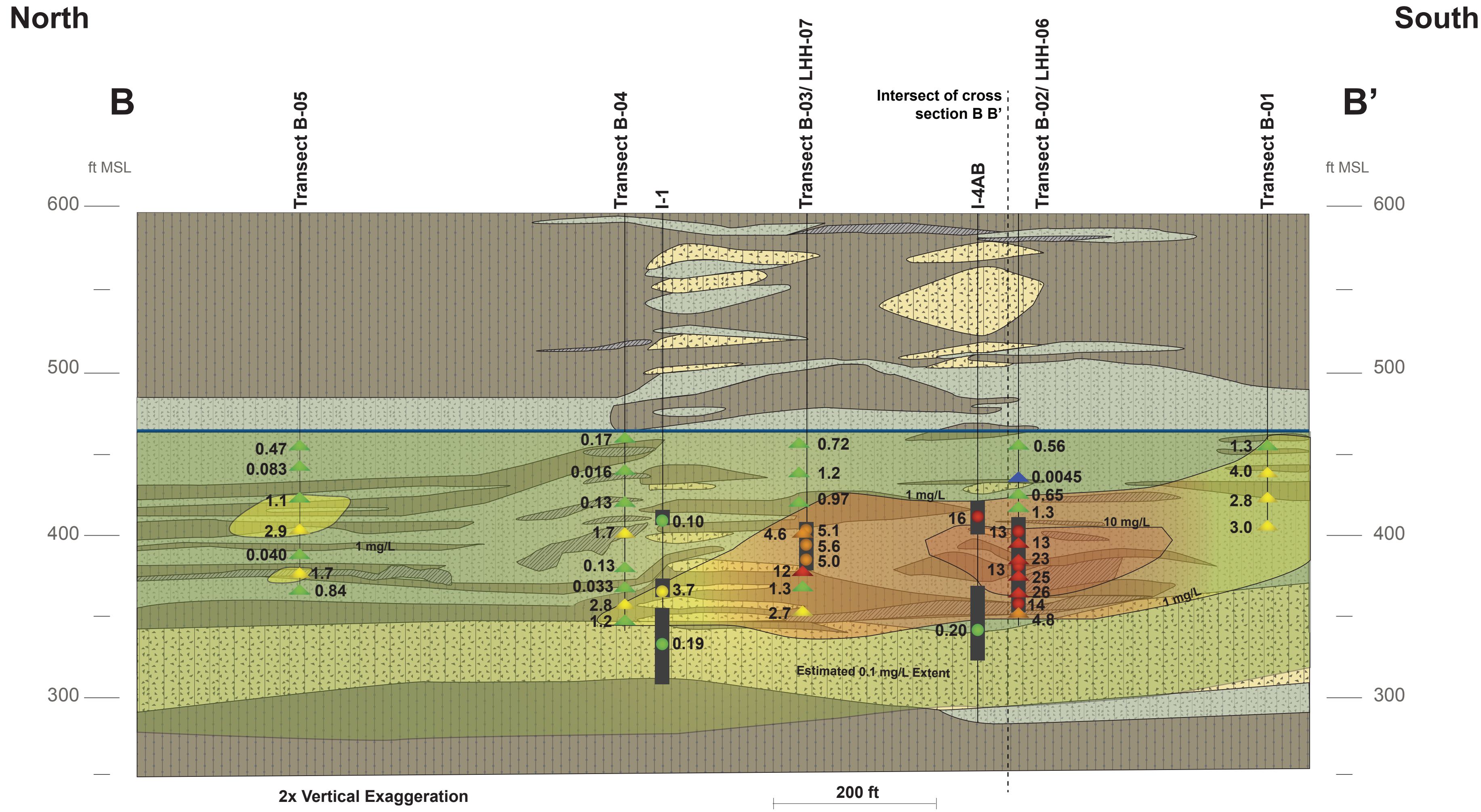
Geologic Cross Section - A-A' Total Chromium
Feasibility Study
Lake Havasu Ave and Holly Ave WQARF Site
Lake Havasu City, Arizona

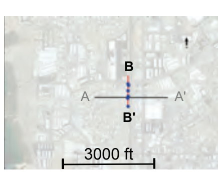
Geosyntec consultants

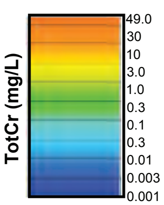
Phoenix | June 2021

Figure 10

figure 11a_2020pw.ai







- Groundwater Surface
- Concentration Isoline
- Well Screen Interval
- Hydropunch Sample
- Groundwater Sample
- Sandy Lean Clay; Sandy Lean Clay with Gravel
- Well/Poorly Graded Gravel; Well/Poorly Graded Gravel with Sand
- Well/Poorly Graded Sand with Clay; Well/Poorly Graded Sand with Clay and Gravel; Silty Sand; Silty Sand with Gravel; Clayey Sand; Clayey Sand with Gravel
- Well/Poorly Graded Sand; Well/Poorly Graded Sand with Gravel

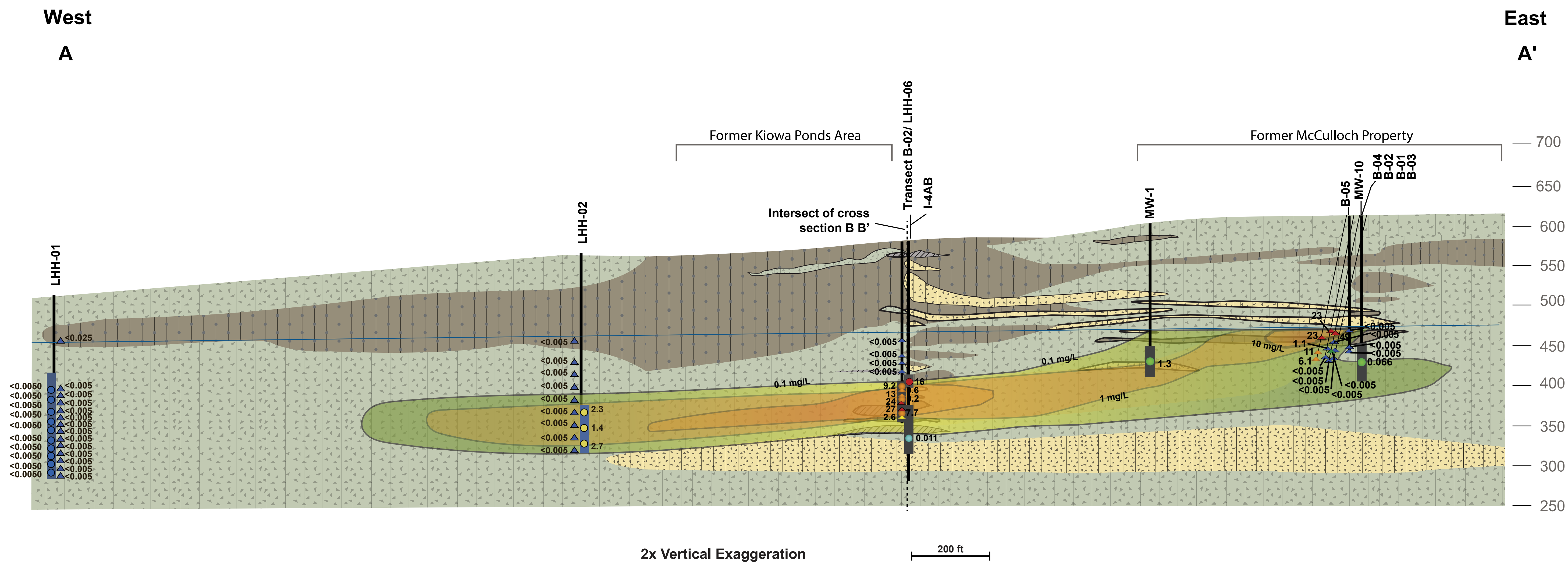
Notes:
- Total Chromium (TotCr) results are plotted using concentration data from 31 wells and borings sampled from March 2014 through April 2019.
- Samples shown without screens were collected as grab samples from borings not completed as monitoring wells.
- Non-detect results are shown at the laboratory reporting limit.
- mg/L = milligrams per liter
- TotCr plume is shown greater than the AWQS of 0.1 mg/L.

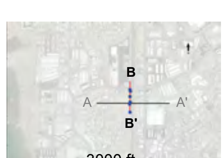
Geologic Cross Section - B-B' Total Chromium
Feasibility Study
Lake Havasu Ave and Holly Ave WQARF Site Lake Havasu City, Arizona

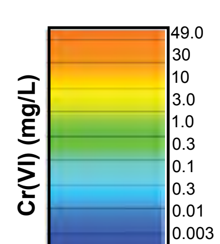
Geosyntec consultants

Figure 11

Phoenix | June 2021







Groundwater Surface Concentration Isoline

Well Screen Interval

Hydropunch Sample

Groundwater Sample

Sandy Lean Clay; Sandy Lean Clay with Gravel

Well/Poorly Graded Gravel; Well/Poorly Graded Gravel with Sand

Well/Poorly Graded Sand with Clay; Well/Poorly Graded Sand with Clay and Gravel; Silty Sand; Silty Sand with Gravel; Clayey Sand; Clayey Sand with Gravel

Well/Poorly Graded Sand; Well/Poorly Graded Sand with Gravel

Notes:
- Hexavalent Chromium (Cr[VI]) results are plotted using concentration data from 31 wells and borings sampled from March 2014 through April 2019.
- Samples shown without screens were collected as grab samples from borings not completed as monitoring wells.
- Non-detect results are shown at the laboratory reporting limit.
- mg/L = milligrams per liter
- Cr(VI) plume is shown greater than 0.1 mg/L (no existing AWQS).

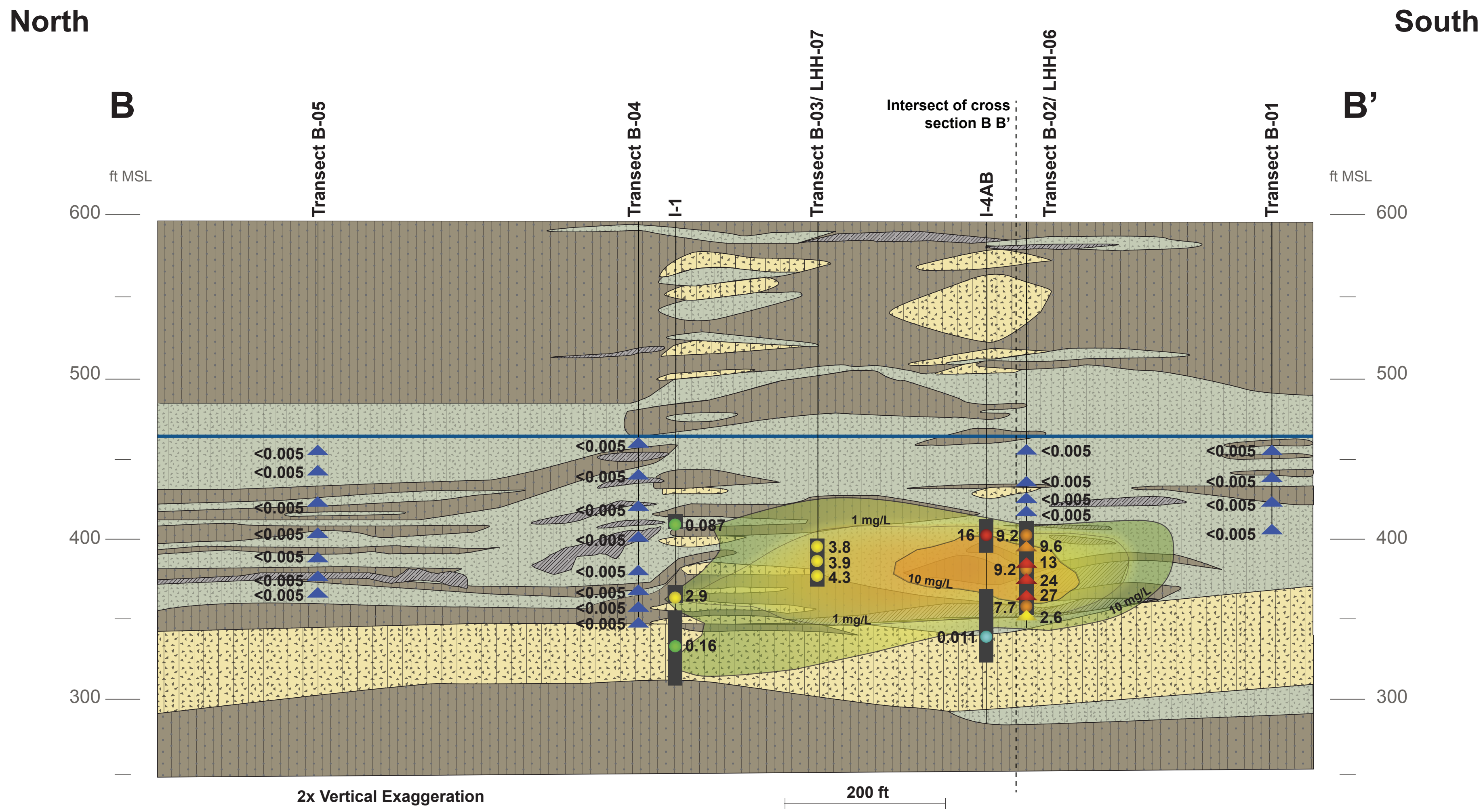
Geologic Cross Section - A-A'
Hexavalent Chromium
Feasibility Study
Lake Havasu Ave and Holly Ave WQARF Site
Lake Havasu City, Arizona

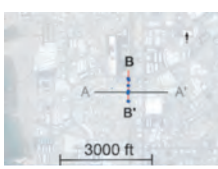
Geosyntec consultants

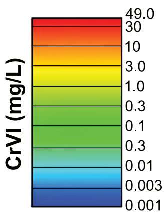
Phoenix	June 2021

Figure 12

figure 12a_2020pw.ai







- Groundwater Surface
- Concentration Isoline
- Well Screen Interval
- Hydropunch Sample
- Groundwater Sample
- Sandy Lean Clay; Sandy Lean Clay with Gravel
- Well/Poorly Graded Gravel; Well/Poorly Graded Gravel with Sand
- Well/Poorly Graded Sand with Clay; Well/Poorly Graded Sand with Clay and Gravel; Silty Sand; Silty Sand with Gravel; Clayey Sand; Clayey Sand with Gravel
- Well/Poorly Graded Sand; Well/Poorly Graded Sand with Gravel

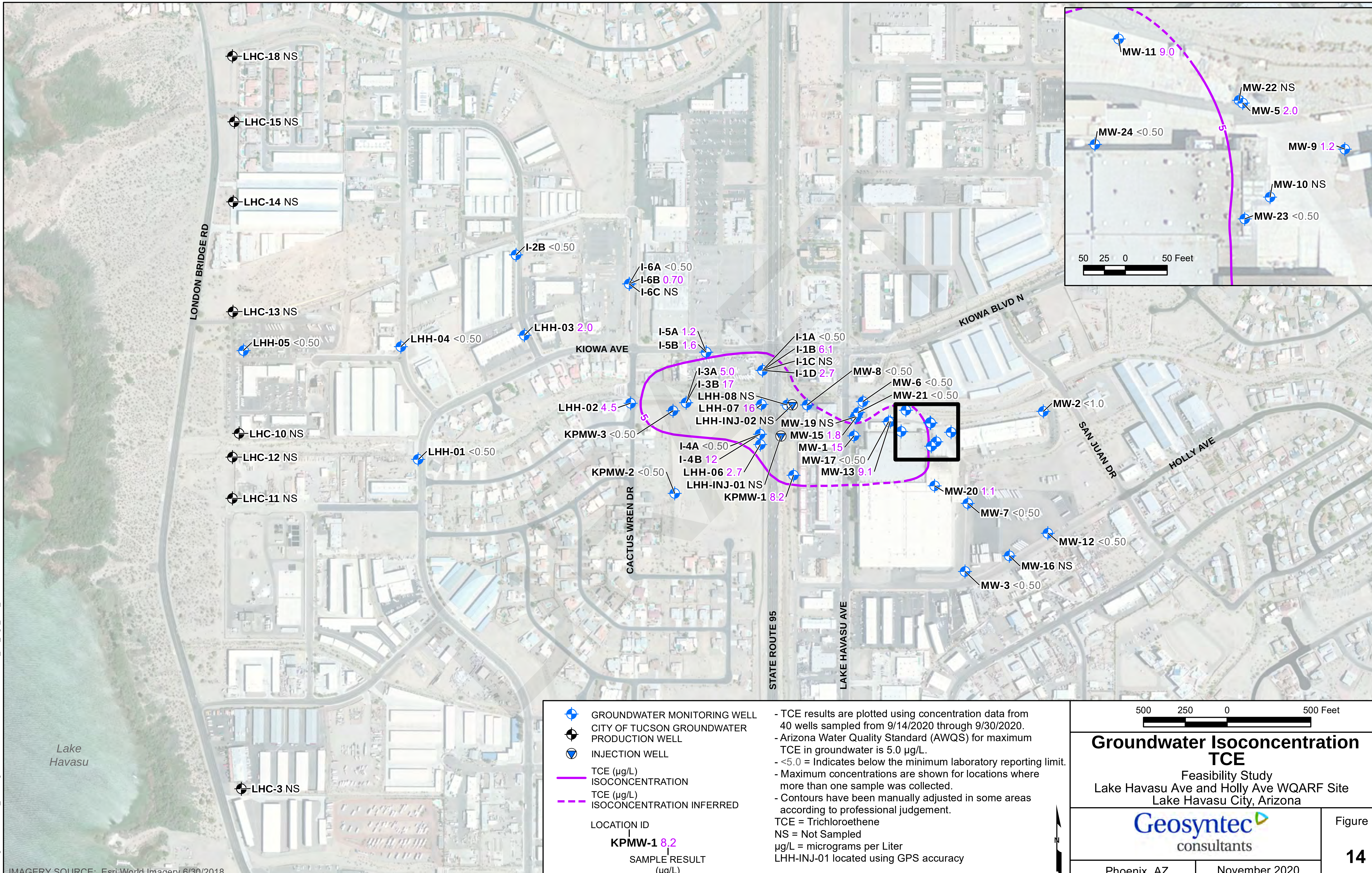
Notes:
- Hexavalent Chromium (CrVI) results are plotted using concentration data from 31 wells and borings sampled from March 2014 through April 2019.
- Samples shown without screens were collected as grab samples from borings not completed as monitoring wells.
- Non-detect results are shown at the laboratory reporting limit.
- mg/L = milligrams per liter
- Cr(VI) plume is shown greater than 0.1 mg/L (no existing AWQS).

Geologic Cross Section - B-B'
Hexavalent Chromium
Feasibility Study
Lake Havasu Ave and Holly Ave WQARF Site Lake Havasu City, Arizona

Geosyntec consultants

Phoenix | June 2021

Figure 13



- TCE results are plotted using concentration data from 40 wells sampled from 9/14/2020 through 9/30/2020.
- Arizona Water Quality Standard (AWQS) for maximum TCE in groundwater is 5.0 µg/L.
- <5.0 = Indicates below the minimum laboratory reporting limit.
- Maximum concentrations are shown for locations where more than one sample was collected.
- Contours have been manually adjusted in some areas according to professional judgement.

TCE = Trichloroethene
NS = Not Sampled
µg/L = micrograms per Liter
LHH-INJ-01 located using GPS accuracy

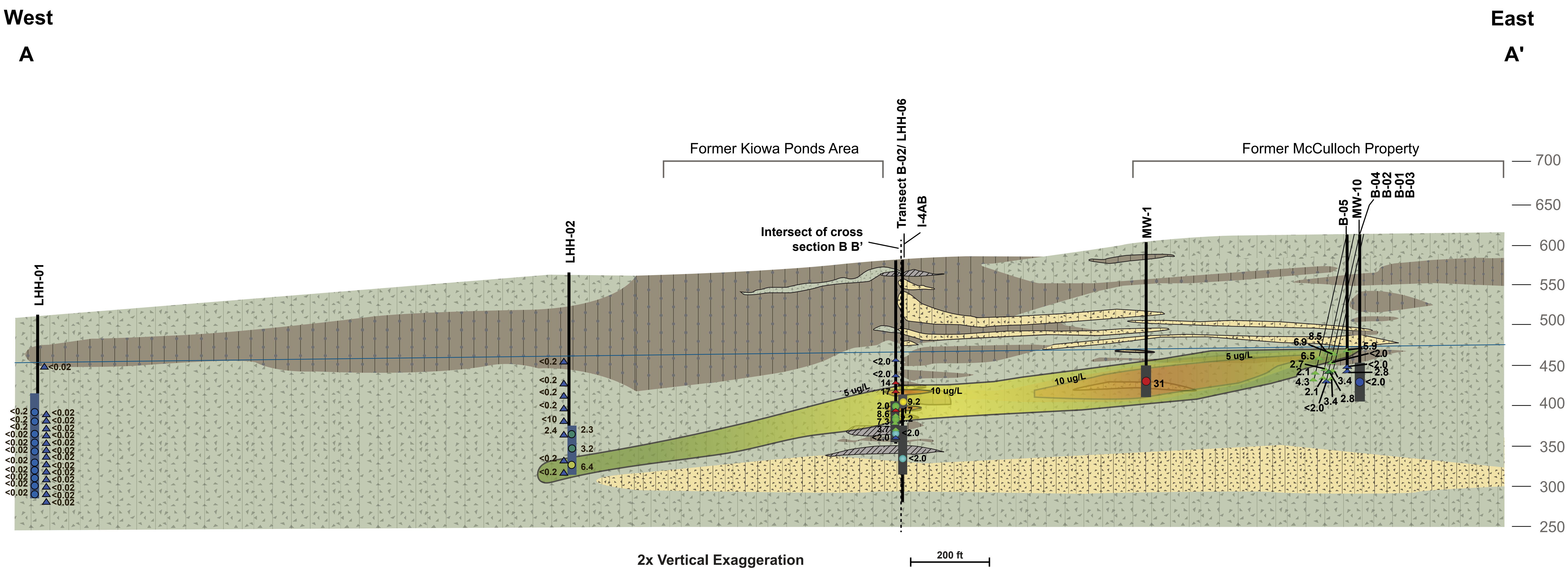
Groundwater Isoconcentration TCE

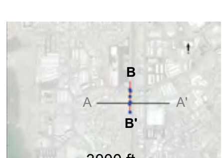
Feasibility Study
Lake Havasu Ave and Holly Ave WQARF Site
Lake Havasu City, Arizona

Geosyntec consultants

Phoenix, AZ | November 2020

Figure 14





TCE (µg L)

31, 1, 3, 1, 0.3

- Groundwater Surface Concentration Isoline
- Well Screen Interval
- Hydropunch Sample
- Groundwater Sample
- Sandy Lean Clay; Sandy Lean Clay with Gravel
- Well/Poorly Graded Gravel; Well/Poorly Graded Gravel with Sand
- Well/Poorly Graded Sand with Clay; Well/Poorly Graded Sand with Clay and Gravel; Silty Sand; Silty Sand with Gravel; Clayey Sand; Clayey Sand with Gravel
- Well/Poorly Graded Sand; Well/Poorly Graded Sand with Gravel

Notes:
- TCE results are plotted using concentration data from 53 wells and borings sampled from March 2014 through April 2019.
- Samples shown without screens were collected as grab samples from borings not completed as monitoring wells.
- Non-detect results are shown at the laboratory reporting limit.
- µg/L = microgram per liter
- TCE plume is shown greater than the AWQS of 5.0 µg/L.

Geologic Cross Section - A-A' TCE Feasibility Study

Lake Havasu Ave and Holly Ave WQARF Site

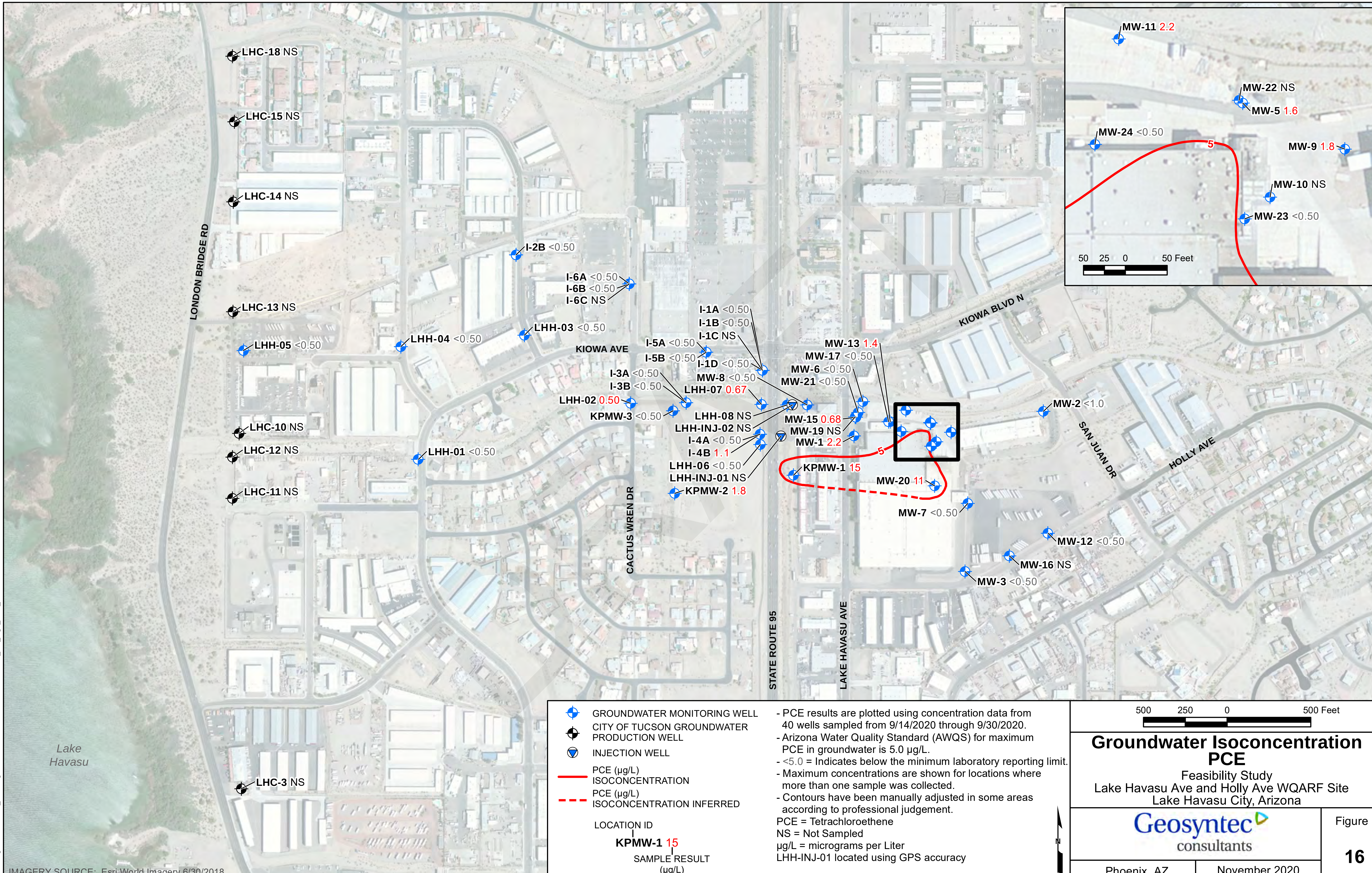
Lake Havasu City, Arizona

Geosyntec consultants

Phoenix | June 2021

Figure 15

figure 13a_2020pw.ai



GROUNDWATER MONITORING WELL
CITY OF TUCSON GROUNDWATER PRODUCTION WELL
INJECTION WELL
PCE (µg/L) ISOCONCENTRATION
PCE (µg/L) ISOCONCENTRATION INFERRED

LOCATION ID
KPMW-1 15
SAMPLE RESULT (µg/L)

- PCE results are plotted using concentration data from 40 wells sampled from 9/14/2020 through 9/30/2020.
- Arizona Water Quality Standard (AWQS) for maximum PCE in groundwater is 5.0 µg/L.
- <5.0 = Indicates below the minimum laboratory reporting limit.
- Maximum concentrations are shown for locations where more than one sample was collected.
- Contours have been manually adjusted in some areas according to professional judgement.

PCE = Tetrachloroethene
NS = Not Sampled
µg/L = micrograms per Liter
LHH-INJ-01 located using GPS accuracy

500 250 0 500 Feet

N

Groundwater Isoconcentration PCE

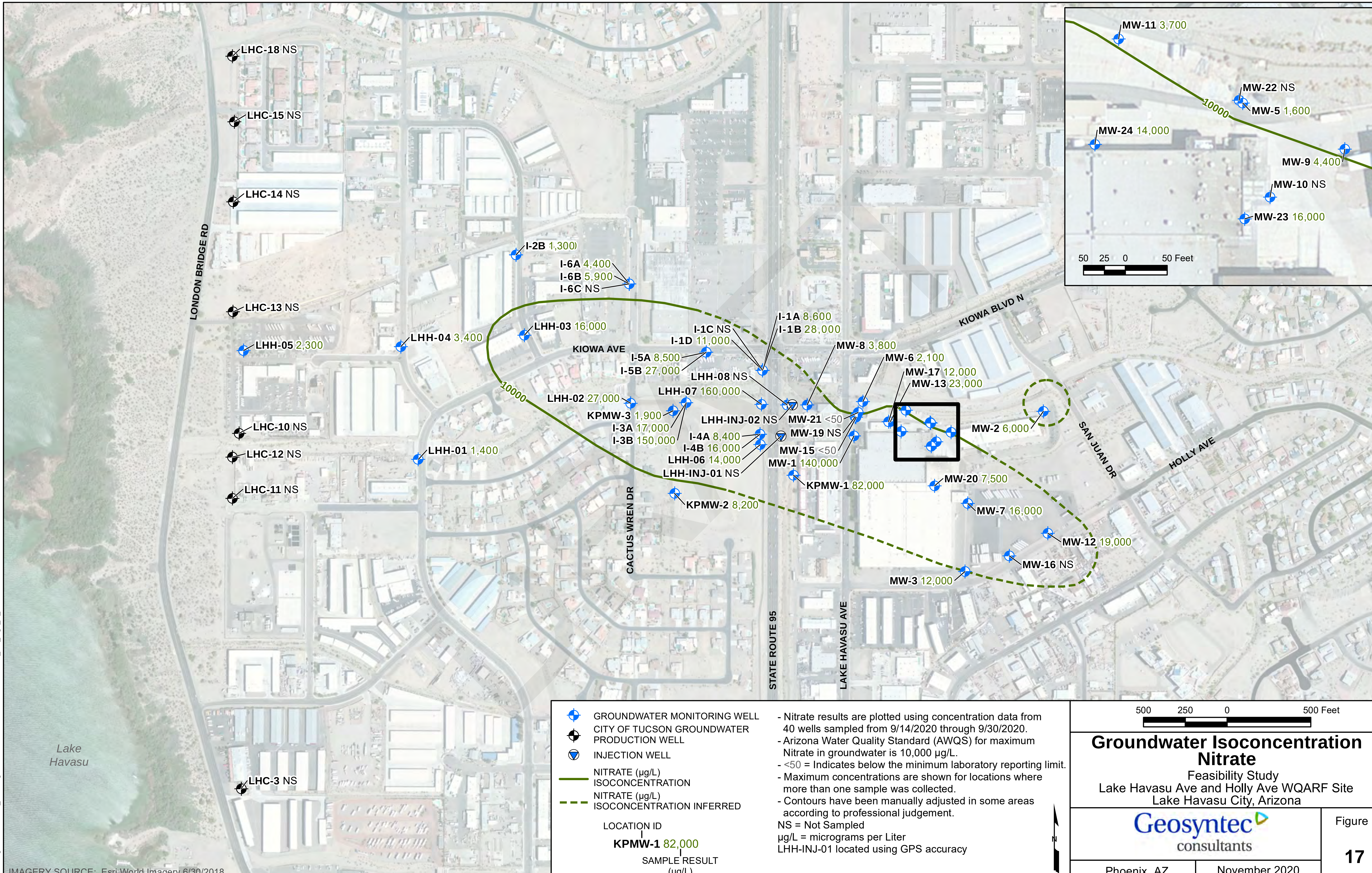
Feasibility Study
Lake Havasu Ave and Holly Ave WQARF Site
Lake Havasu City, Arizona

Geosyntec consultants

Figure 16

Phoenix, AZ | November 2020

\\SanDiego-01\Data\GIS_SanDiego01\SP0164\MXD\GWM\2020\Havasu_TM_Fig4_PCE_202003.mxd SWolfskill 11/11/2020



GROUNDWATER MONITORING WELL

CITY OF TUCSON GROUNDWATER PRODUCTION WELL

INJECTION WELL

NITRATE (µg/L) ISOCONCENTRATION

NITRATE (µg/L) ISOCONCENTRATION INFERRED

LOCATION ID

KPMW-1 82,000

SAMPLE RESULT (µg/L)

- Nitrate results are plotted using concentration data from 40 wells sampled from 9/14/2020 through 9/30/2020.
- Arizona Water Quality Standard (AWQS) for maximum Nitrate in groundwater is 10,000 µg/L.
- <50 = Indicates below the minimum laboratory reporting limit.
- Maximum concentrations are shown for locations where more than one sample was collected.
- Contours have been manually adjusted in some areas according to professional judgement.

NS = Not Sampled

µg/L = micrograms per Liter

LHH-INJ-01 located using GPS accuracy

N

500 250 0 500 Feet

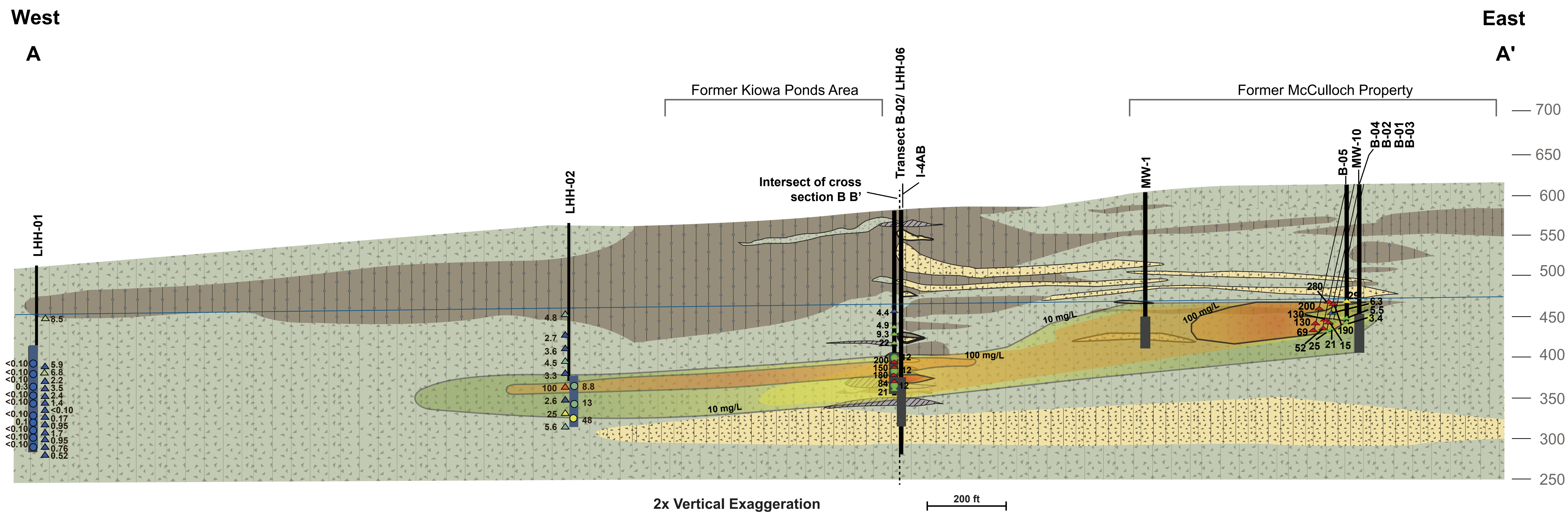
Groundwater Isoconcentration Nitrate

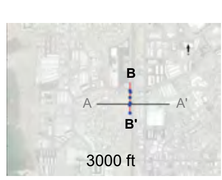
Feasibility Study
Lake Havasu Ave and Holly Ave WQARF Site
Lake Havasu City, Arizona

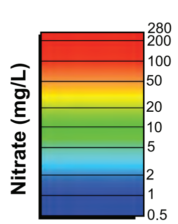
Geosyntec consultants

Figure 17

Phoenix, AZ | November 2020







- Groundwater Surface
- Concentration Isoline
- Well Screen Interval
- Hydropunch Sample
- Groundwater Sample
- Sandy Lean Clay; Sandy Lean Clay with Gravel
- Well/Poorly Graded Gravel; Well/Poorly Graded Gravel with Sand
- Well/Poorly Graded Sand with Clay; Well/Poorly Graded Sand with Clay and Gravel; Silty Sand; Silty Sand with Gravel; Clayey Sand; Clayey Sand with Gravel
- Well/Poorly Graded Sand; Well/Poorly Graded Sand with Gravel

Notes:
- Nitrate results are plotted using concentration data from 31 wells and borings sampled from March 2014 through April 2019.
- Samples shown without screens were collected as grab samples from borings not completed as monitoring wells.
- Non-detect results are shown at the laboratory reporting limit.
- mg/L = milligrams per liter
- Nitrate plume is shown greater than the AWQS of 10 mg/L.

Geologic Cross Section - A-A' Nitrate

Feasibility Study

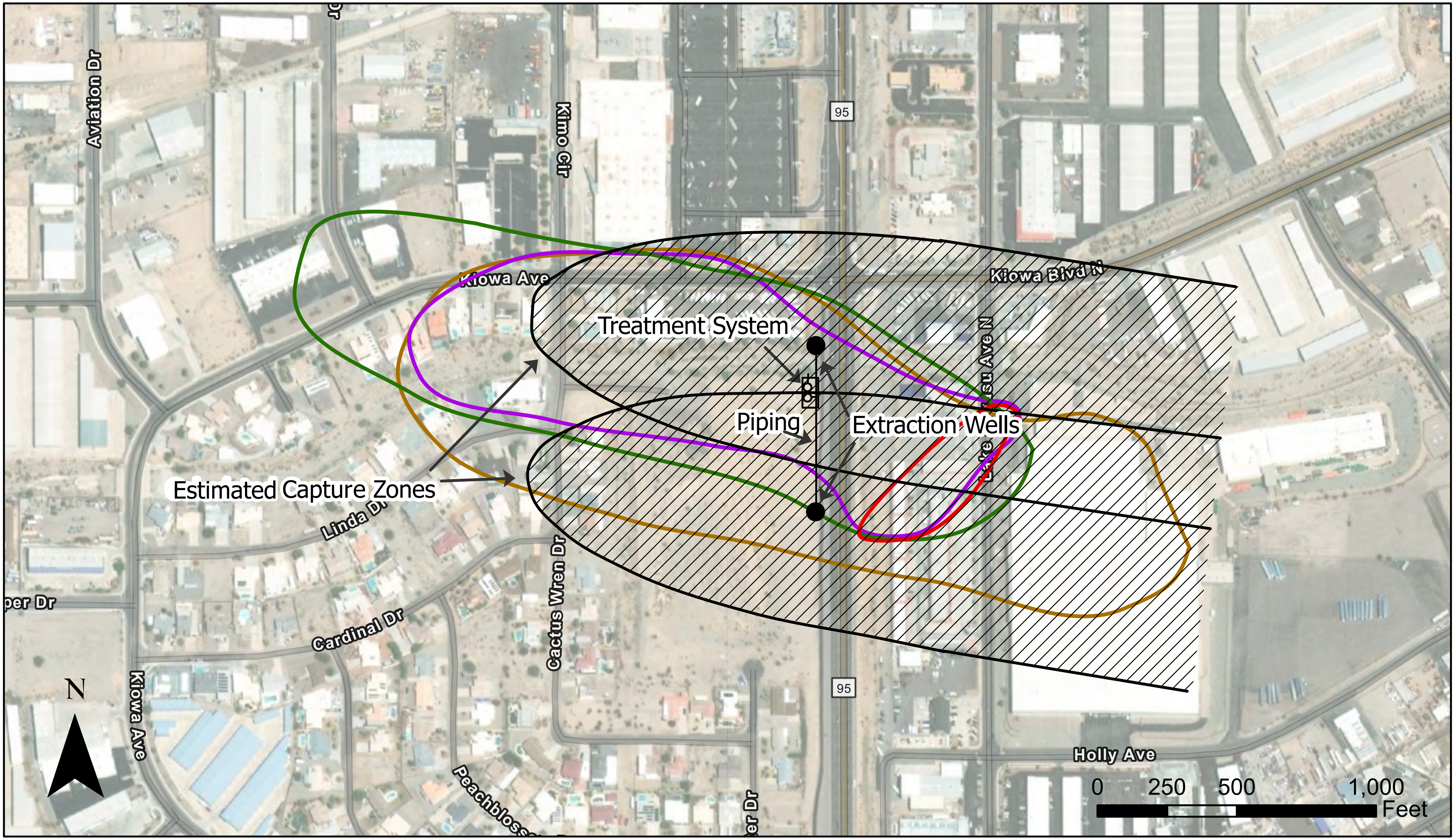
Lake Havasu Ave and Holly Ave WQARF Site
Lake Havasu City, Arizona

Geosyntec consultants

Figure 18

Phoenix | June 2020

figure 14a_2020pw.ai



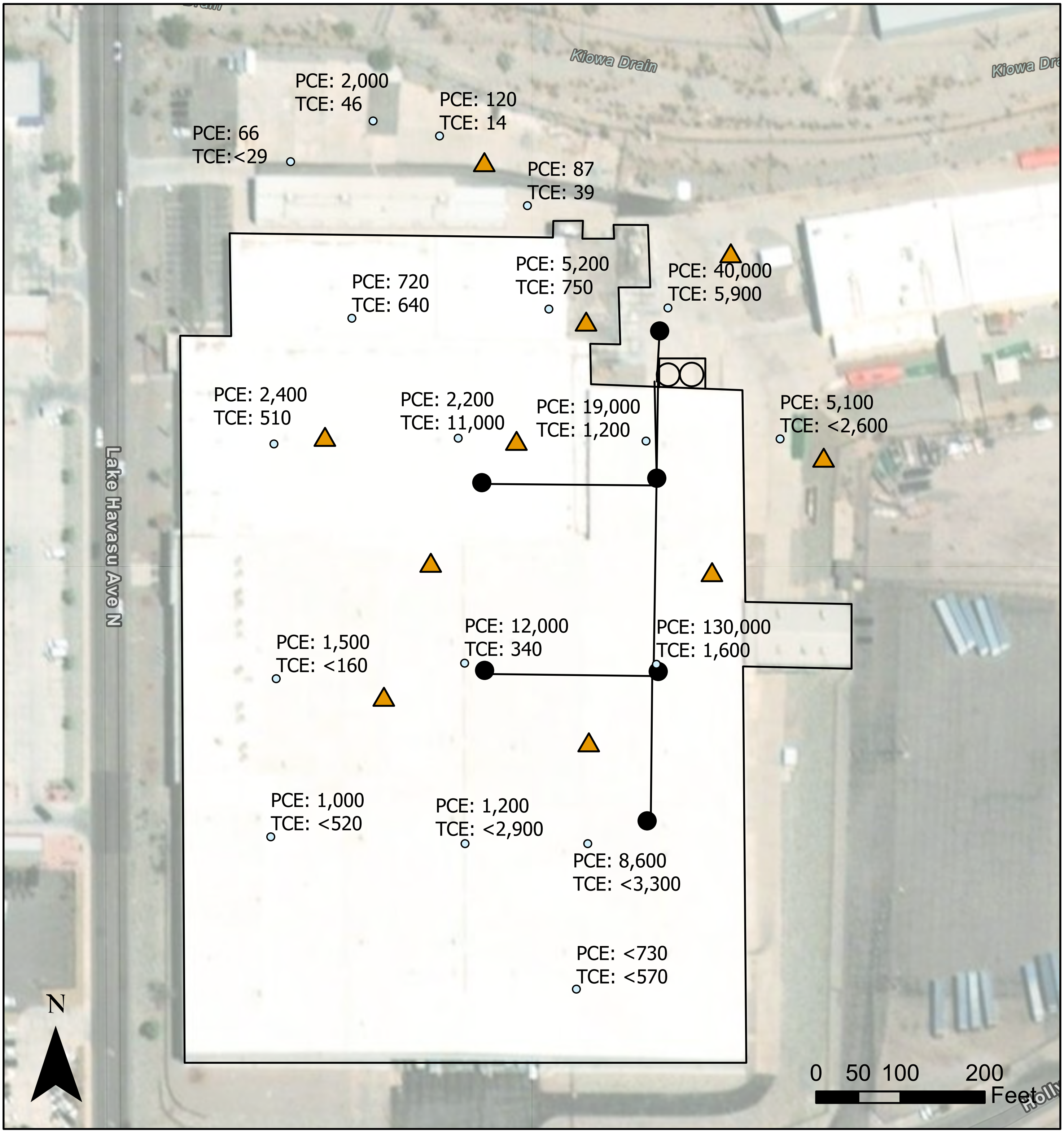
Groundwater Plume Extents, 2020

- Chromium
- Nitrate
- Trichloroethene
- Tetrachloroethene

ADEQ
Arizona Department of Environmental Quality

Figure 19
Reference Remedy Conceptual GETS Layout

Lake Havasu Avenue and Holly Avenue Feasibility Study



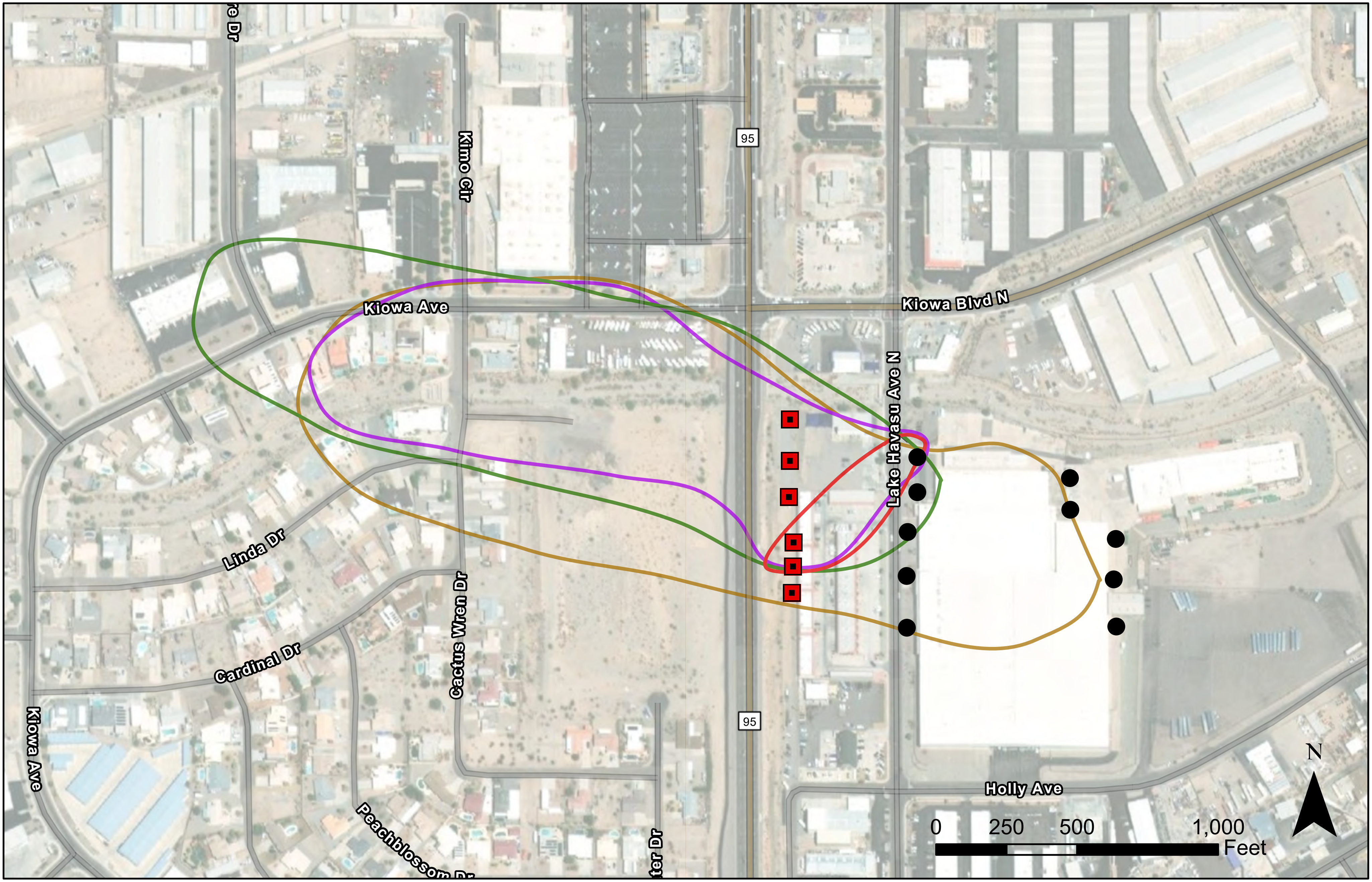
Legend

- Soil Gas Location with Maximum PCE and TCE Result
- Conceptual Soil Vapor Extraction Well
- Conceptual Soil Vapor Monitoring Point
- Conceptual Underground Piping
- Conceptual SVE System

Figure 20
Conceptual SVE System Layout

Lake Havasu Avenue and Holly Avenue
Feasibility Study

ADEQ
Arizona Department of Environmental Quality



Legend

Current Injection Wells

Conceptual Injection Wells

Groundwater Plume Extents, 2020

Chromium

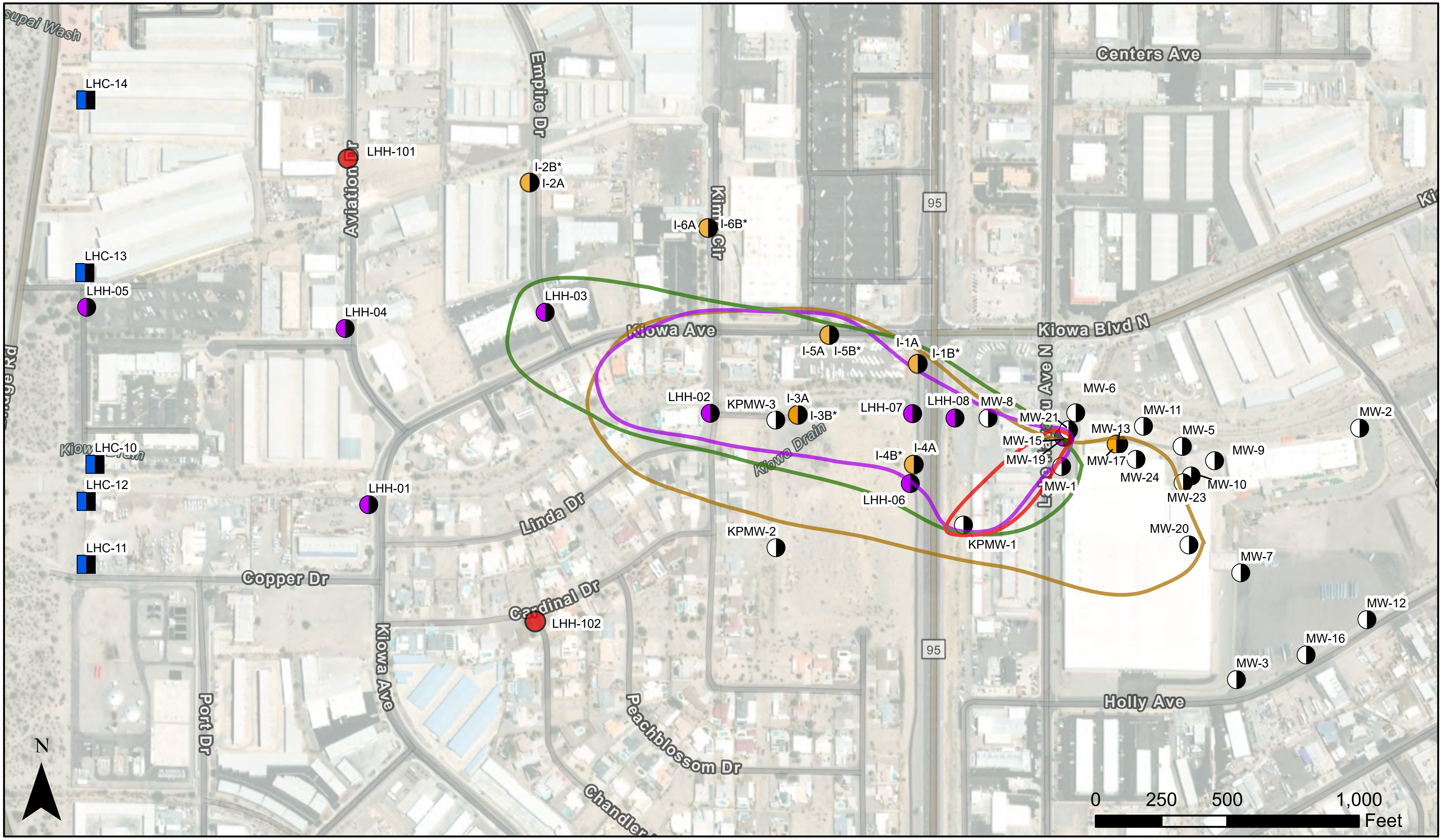
Nitrate

Trichloroethene

Tetrachloroethene

ADEQ
Arizona Department of Environmental Quality

Figure 21
More Aggressive Remedy
Conceptual In-Situ Bio
Locations
Lake Havasu Avenue and Holly Avenue
Feasibility Study



Legend

Wells

- Deep Monitoring Well
- Medium Monitoring Well
- Shallow Monitoring Well
- Conceptual Future Monitoring Well
- Lake Havasu City Backup Supply Wells

Groundwater Plume Extents, 2020

- Chromium
- Nitrate
- Trichloroethene
- Tetrachloroethene

Note: B designations are shallow wells nested with medium wells

ADEQ
Arizona Department of Environmental Quality

Figure 22
Less Aggressive Remedy
Conceptual Monitoring Locations
Lake Havasu Avenue and Holly Avenue
Feasibility Study

APPENDIX A
Detailed Cost Sheets for Remedial Alternatives

Estimated Costs for Reference Remedy
Lake Havasu Avenue and Holly Avenue WQARF Site Feasibility Study
Lake Havasu City, Arizona

	Quantity	Units	Cost Per Unit	Total Cost	Total Cost (-30%)	Total Cost (+30%)
Vadose Zone Remedial Measures (VOCs Only) - Construction of SVE System, Operation & Maintenance						
Estimated Capital Costs						
Six SVE Wells (including vertical profile sampling and installation oversight)	6	EA	$48,200	$289,200	$202,440	$375,960
Twelve Dual-Nested Soil Vapor Probes (including installation oversight)	12	EA	$6,500	$78,000	$54,600	$101,400
IDW Management/Disposal (Assumes 2 Rolloff Bins of Non-Haz IDW)	1	LS	$10,000	$10,000	$7,000	$13,000
Complete SVE Installation (Electrical and Piping Connections)	1	LS	$125,000	$125,000	$87,500	$162,500
Capital Costs Subtotal				**$502,200**	**$351,540**	**$652,860**
Estimated Annual O&M Costs (Assumes Four-Year Operation)						
SVE Blower System Rental	12	MO	$3,450	$41,400	$28,980	$53,820
SVE Carbon VGAC Vessel Rental	12	MO	$920	$11,040	$7,728	$14,352
SVE System O&M (2X per month)	12	MO	$3,450	$41,400	$28,980	$53,820
SVE System Site-Wide Vapor Sampling (Assume 2 events/Year)	2	EA	$17,250	$34,500	$24,150	$44,850
SVE System Repair	1	YR	$3,450	$3,450	$2,415	$4,485
Utilities (Electric)	12	MO	$2,300	$27,600	$19,320	$35,880
VGAC Changeout (assumes 1 changeout/year)	1	LS	$11,500	$11,500	$8,050	$14,950
Miscellaneous Field Supplies	1	LS	$1,150	$1,150	$805	$1,495
Annual O&M Subtotal				**$172,040**	**$120,428**	**$223,652**
Total O&M Costs for Four Years (Assumes 3% Annual Inflation)				**$719,751**	**$503,826**	**$935,677**
Total Estimated Vadose Zone Remedy Costs				**$1,221,951**	**$855,366**	**$1,588,537**
Groundwater Remedial Measures - GETS, GETS O&M, and MNA Monitoring of Existing Well Network						
Estimated Capital Costs						
Groundwater Extraction Wells						
Installation, Development & Well-Head Completion of Two Extraction Wells (Drilling, Oversight, IDW, Survey, Traffic Control, Permitting)	2	EA	$201,250	$402,500	$281,750	$523,250
GW extraction well down-hole components (pump,controller, piping)	2	EA	$17,250	$34,500	$24,150	$44,850
GETS System for up to 200 GPM Flow Rate (assumes modular skid-based components)						
Slab-On-Grade Treatment Compound (foundation, fence, power, etc.)	1600	SF	$110	$176,000	$123,200	$228,800
Multi-Media Filter System	1	LS	$105,410	$105,410	$73,787	$137,033
LGAC system	1	LS	$140,970	$140,970	$98,679	$183,261
Nitrate Removal Ion Exchange Resin System	1	LS	$444,500	$444,500	$311,150	$577,850
Chromium Removal Ion Exchange Resin System	1	LS	$733,870	$733,870	$513,709	$954,031
HDPE Conveyance Piping Installed	1900	LF	$254	$482,600	$337,820	$627,380
Electrical and Instrumentation (20% of Equipment Cost)	20%	n/a	n/a	$388,370	$271,859	$504,881
Capital Costs Subtotal				**$2,908,720**	**$2,036,104**	**$3,781,336**
Estimated Annual Costs for GETS O&M (Assumes 30-Year Operation)						
GETS O&M/Reporting	1	LS	$138,000	$138,000	$96,600	$179,400
Electric Power	12	Monthly	$5,750	$69,000	$48,300	$89,700
LGAC Changeout	1	LS	$39,100	$39,100	$27,370	$50,830
Nitrate Ion Exchange Resin Changeout	1	LS	$120,750	$120,750	$84,525	$156,975
Chromium Ion Exchange Resin Changeout	1	LS	$157,550	$157,550	$110,285	$204,815
Annual O&M and Monitoring Subtotal				**$524,400**	**$367,080**	**$681,720**
Total GETS O&M for 30 Years (Assumes 3% Annual Inflation)				**$24,948,548**	**$17,463,984**	**$32,433,112**
Estimated Annual Costs for Groundwater Monitoring (Assumes 30-Year Monitoring)						
Semiannual Groundwater Monitoring/Reporting	2	Ea	$86,250	$172,500	$121,000	$259,000
Annual Groundwater Monitoring Subtotal				**$172,500**	**$120,750**	**$224,250**
Total Groundwater Monitoring for 30 Years (Assumes 3% Annual Inflation)				**$8,206,759**	**$5,744,731**	**$10,668,787**
Total Estimated Groundwater Reference Remedy				**$36,064,027**	**$25,244,819**	**$46,883,235**
Estimated Groundwater Reference Remedy Contingency Costs						
Two-Years of ISB at Source Area (Assumes Four ISB Wells Installed at Source Area)	1	YR	$1,370,000	$1,370,000	$959,000	$1,781,000
Five-Years of Additional GETS Operation and Monitoring (Assumes 3% Annual Inflation)	5	YR	NA	$8,719,143	$6,103,400	$11,334,886
Groundwater Contingency Costs Subtotal				**$10,089,143**	**$7,062,400**	**$13,115,886**
Total Estimated Groundwater Reference Remedy and Contingency Costs				**$46,153,171**	**$32,307,219**	**$59,999,122**
REFERNCE REMEDY COSTS (NO CONTINGENCIES)				**$37,285,978**	**$26,100,185**	**$48,471,772**
REFERNCE REMEDY CONTINGENCY COSTS				**$10,089,143**	**$7,062,400**	**$13,115,886**
REFERNCE REMEDY COSTS (INCLUDING CONTINGENCY)				**$47,375,122**	**$33,162,585**	**$61,587,658**

Abbreviations:

WQARF = Water Quality Assurance Revolving Fund
% = percent
LS = lump sum
$ = United States dollars
bgs = below ground surface
SVE = soil vapor extraction
O&M = operations and maintenance
GETS = groundwater extraction and treatment system
EA = each
LGAC = liquid phase granular activated carbon
LF = linear feet
IDW = Investigation-derived waste
ISB = in-situ bioremediation

Notes:

1. Pricing is subject to commodity pricing increases. Contingencies for possible price escalation due to steel or other tariffs is not included.
2. No estimated costs have been included for taxes or other fees relative to the project.

Estimated Costs for More Aggressive Remedy
Lake Havasu Avenue and Holly Avenue WQARF Site Feasibility Study
Lake Havasu City, Arizona

	Quantity	Units	Cost Per Unit	Total Cost	Total Cost (-30%)	Total Cost (+30%)
Vadose Zone Remedial Measures (VOCs Only) - Construction of SVE System and O&M						
Estimated Capital Costs						
Five SVE Wells (including vertical profile sampling and installation oversight)	6	EA	$48,200	$289,200	$202,440	$375,960
Ten Dual-Nested Soil Vapor Probes	12	EA	$6,500	$78,000	$54,600	$101,400
IDW Management/Disposal (Assumes 2 Rolloff Bins of Non-Haz IDW)	1	LS	$10,000	$10,000	$7,000	$13,000
Complete SVE Installation (Electrical and Piping Connections)	1	LS	$125,000	$125,000	$87,500	$162,500
Capital Costs Subtotal				**$502,200**	**$351,540**	**$652,860**
Estimated Annual O&M Costs (Assumes Four-Year Operation)						
SVE Blower System Rental	12	MO	$3,450	$41,400	$28,980	$53,820
SVE Carbon VGAC Vessel Rental	12	MO	$920	$11,040	$7,728	$14,352
SVE System O&M (2X per month)	12	MO	$3,450	$41,400	$28,980	$53,820
SVE System Site-Wide Vapor Sampling (Assume 2 events/Year)	2	EA	$17,250	$34,500	$24,150	$44,850
SVE System Repair	1	YR	$3,450	$3,450	$2,415	$4,485
Utilities (Electric)	12	MO	$2,300	$27,600	$19,320	$35,880
VGAC Changeout (assumes 1 changeout/year)	1	LS	$11,500	$11,500	$8,050	$14,950
Miscellaneous Field Supplies	1	LS	$1,150	$1,150	$805	$1,495
Annual O&M Subtotal				**$172,040**	**$120,428**	**$223,652**
Total O&M Costs for Four Years (Assumes 3% Annual Inflation)				**$719,751**	**$503,826**	**$935,677**
Total Estimated Vadose Zone Remedy Costs				**$1,221,951**	**$855,366**	**$1,588,537**
Groundwater Remedial Measures - ISB, ISB O&M, and MNA Monitoring of Existing Well Network						
Estimated Capital Costs						
ISB Injection Wells						
Installation of 10 ISB Injection Wells (Permitting, Drilling, Surveying, & Oversight)	10	EA	$95,450	$954,500	$668,150	$1,240,850
IDW for ISB well Installations (per well)	10	EA	$5,750	$57,500	$40,250	$74,750
ISB System (Tanks, Pumps, Associated Infrastructure)						
ISB System Compound (fencing, Site prep etc.)	1	LS	$28,750	$28,750	$20,125	$37,375
Frac-Tanks (20,000-gallon capacity)- Rental Cost	3	YR	$17,250	$51,750	$36,225	$67,275
Dosatrons (Injectors for controlling injectate solution concentration)	2	LS	$3,450	$6,900	$4,830	$8,970
Manifold Assembly for Injectate Delivery	1	LS	$34,500	$34,500	$24,150	$44,850
Conveyance piping installed from ISB compound to injection wells	2400	EA	$23	$55,200	$38,640	$71,760
Capital Costs Subtotal				**$1,189,100**	**$832,370**	**$1,545,830**
Estimated Annual Costs for ISB O&M (Assumes Four-Year Program)						
ISB O&M/Reporting	1	YR	$155,250	$155,250	$108,675	$201,825
HFCS (per Gallon)	30000	EA	$5.75	$172,500	$120,750	$224,250
EVO (per Gallon)	30000	EA	$9.20	$276,000	$193,200	$358,800
LHC Potable Water for Donor Solution (per gallon)	3000000	EA	$0.02	$60,000	$42,000	$78,000
Field Supplies	1	LS	$11,500	$11,500	$8,050	$14,950
Annual ISB O&M and Monitoring Subtotal				**$675,250**	**$472,675**	**$877,825**
Total ISB Injection Program O&M for Four Years (Assumes 3% Annual Inflation)				**$2,824,994**	**$1,977,496**	**$3,672,492**
Estimated Annual Costs for Groundwater Monitoring (Assumes Nine-Year Monitoring)						
Semiannual Groundwater Monitoring/Reporting (Including laboratory analytical)	2	Ea	$86,250	$172,500	$120,750	$224,250
Annual Groundwater Monitoring Subtotal				**$172,500**	**$120,750**	**$224,250**
Total Cost for Nine Years Groundwater Monitoring (Assumes 3% Annual Inflation)				**$1,752,446**	**$1,226,712**	**$2,278,180**
Total Estimated Groundwater More Aggressive Remedy Costs				**$5,766,540**	**$4,036,578**	**$7,496,502**
Estimated Groundwater Contingency Costs						
Wellhead Treatment at LHH Wells (two separate systems)						
Three (3) parallel lead/lag treatment systems with 10,000-lb ion exchange contactors	6	EA	$266,667	$1,600,000	$1,120,000	$2,080,000
Chemical injection system for pH adjustment	2	LS	$100,000	$200,000	$140,000	$260,000
Initial load of ion exchange resin (est. $700k) and pH chemicals ($10k)	2	LS	$710,000	$1,420,000	$994,000	$1,846,000
Site preparation, infrastructure, control equipment	2	LS	$1,500,000	$3,000,000	$2,100,000	$3,900,000
Engineering and construction	2	LS	$400,000	$800,000	$560,000	$1,040,000
Ion exchange resin changeout (assumed reoccurs every 5 years)	4	EA	$375,000	$1,500,000	$1,050,000	$1,950,000
pH chemicals (assumed needed annually)	20	EA	$15,000	$300,000	$210,000	$390,000
Groundwater Contingency Costs Subtotal				**$8,820,000**	**$6,174,000**	**$11,466,000**
Total Estimated Groundwater More Aggressive Remedy Costs With Contingencies				**$14,586,540**	**$10,210,578**	**$18,962,502**
MORE AGGRESSIVE REMEDY COSTS (NO CONTINGENCIES)				**$6,988,491**	**$4,891,944**	**$9,085,038**
MORE AGGRESSIVE REMEDY CONTINGENCY COSTS				**$8,820,000**	**$6,174,000**	**$11,466,000**
MORE AGGRESSIVE REMEDY COSTS (INCLUDING ALL CONTINGENCIES)				**$15,808,491**	**$11,065,944**	**$20,551,038**

Abbreviations:
Abbreviations:

WQARF = Water Quality Assurance Revolving Fund
% = percent
LS = lump sum
$ = United States dollars
bgs = below ground surface
SVE = soil vapor extraction
O&M = operations and maintenance
ISB = in-situ bioremediation
EA = each
IDW = Investigation-derived waste
LF = linear feet
IDW = Investigation-derived waste
EVO = emulsified vegetable oil
HFCS = high fructose corn syrup

Notes:
1. Pricing is subject to commodity pricing increases. Contingencies for possible price escalation due to steel or other tariffs is not included.
2. No estimated costs have been included for taxes or other fees relative to the project.

Estimated Costs for Less Aggressive Remedy
Lake Havasu Avenue and Holly Avenue WQARF Site Feasibility Study
Lake Havasu City, Arizona

	Quantity	Units	Cost Per Unit	Total Cost	Total Cost (-30%)	Total Cost (+30%)
Vadose Zone Remedial Measures (VOCs Only) - Construction of SVE System, Operation & Maintenance						
Estimated Capital Costs						
Five SVE Wells (including vertical profile sampling and installation oversight)	6	EA	$48,200	$289,200	$202,440	$375,960
Ten Dual-Nested Soil Vapor Probes	12	EA	$6,500	$78,000	$54,600	$101,400
IDW Management/Disposal (Assumes 2 Rolloff Bins of Non-Haz IDW)	1	LS	$10,000	$10,000	$7,000	$13,000
Complete SVE Installation (Electrical and Piping Connections)	1	LS	$125,000	$125,000	$87,500	$162,500
Capital Costs Subtotal				**$502,200**	**$351,540**	**$652,860**
Estimated Annual O&M Costs (Assumes Four-Year Operation)						
SVE Blower System Rental	12	MO	$3,450	$41,400	$28,980	$53,820
SVE Carbon VGAC Vessel Rental	12	MO	$920	$11,040	$7,728	$14,352
SVE System O&M (2X per month)	12	MO	$3,450	$41,400	$28,980	$53,820
SVE System Site-Wide Vapor Sampling (Assume 2 events/Year)	2	EA	$17,250	$34,500	$24,150	$44,850
SVE System Repair	1	YR	$3,450	$3,450	$2,415	$4,485
Utilities (Electric)	12	MO	$2,300	$27,600	$19,320	$35,880
VGAC Changeout (assumes 1 changeout/year)	1	LS	$11,500	$11,500	$8,050	$14,950
Miscellaneous Field Supplies	1	LS	$1,150	$1,150	$805	$1,495
Annual O&M Subtotal				**$172,040**	**$120,428**	**$223,652**
Total O&M Costs for Four Years (Assumes 3% Annual Inflation)				**$719,751**	**$503,826**	**$935,677**
Total Estimated Vadose Zone Remedy Costs				**$1,221,951**	**$855,366**	**$1,588,537**
Groundwater Remedial Measures - MNA Monitoring of Existing Well Network						
Estimated Capital Costs						
Installation of two additional monitoring wells	2	Ea	$95,000	$190,000	$133,000	$247,000
Estimated Annual Costs for Groundwater Monitoring (Assumes 30-Year Monitoring)						
Semiannual Groundwater Monitoring/Reporting	2	Ea	$92,000	$184,000	$128,800	$239,200
Annual MNA Groundwater Monitoring Subtotal				**$184,000**	**$128,800**	**$239,200**
Total Groundwater Monitoring for 30 Years (Assumes 3% Annual Inflation)				**$8,753,876**	**$6,127,714**	**$11,380,039**
Total Estimated Groundwater Less Aggressive Remedy Costs				**$8,943,876**	**$6,260,714**	**$11,627,039**
Estimated Groundwater Contingency Costs						
<u>Wellhead Treatment at LHH Wells (two separate systems)</u>						
Three (3) parallel lead/lag treatment systems with 10,000-lb ion exchange contactors	6	EA	$266,667	$1,600,000	$1,120,000	$2,080,000
Chemical injection system for pH adjustment	2	LS	$100,000	$200,000	$140,000	$260,000
Initial load of ion exchange resin (est. $700k) and pH chemicals ($10k)	2	LS	$710,000	$1,420,000	$994,000	$1,846,000
Site preparation, infrastructure, control equipment	2	LS	$1,500,000	$3,000,000	$2,100,000	$3,900,000
Engineering and construction	2	LS	$400,000	$800,000	$560,000	$1,040,000
Ion exchange resin changeout (assumed reoccurs every 5 years)	12	EA	$375,000	$4,500,000	$3,150,000	$5,850,000
pH chemicals (assumed needed annually)	60	EA	$15,000	$900,000	$630,000	$1,170,000
<u>Contingency ISB</u>						
Capital Costs for ISB System Implementation	1	LS	$1,189,100	$1,189,100	$832,370	$1,545,830
Two-Years of ISB O&M	2	YR	$675,250	$1,350,500	$945,350	$1,755,650
Groundwater Contingency Costs Subtotal				**$14,959,600**	**$10,471,720**	**$19,447,480**
Total Estimated Groundwater Less Aggressive Remedy Costs With Contingencies				**$23,903,476**	**$16,732,434**	**$31,074,519**
LESS AGGRESSIVE REMEDY COSTS (NO CONTINGENCIES)				**$10,165,828**	**$7,116,079**	**$13,215,576**
LESS AGGRESSIVE REMEDY CONTINGENCY COSTS				**$14,959,600**	**$10,471,720**	**$19,447,480**
LESS AGGRESSIVE REMEDY COSTS (INCLUDING CONTINGENCY)				**$25,125,428**	**$17,587,799**	**$32,663,056**

Abbreviations:

WQARF = Water Quality Assurance Revolving Fund
% = percent
LS = lump sum
$ = United States dollars
bgs = below ground surface
SVE = soil vapor extraction
O&M = operations and maintenance
GETS = groundwater extraction and treatment system
EA = each
LGAC = liquid phase granular activated carbon
LF = linear feet
IDW = Investigation-derived waste
ISB = in-situ bioremediation

Notes:

1. Pricing is subject to commodity pricing increases. Contingencies for possible price escalation due to steel or other tariffs is not included.
2. No estimated costs have been included for taxes or other fees relative to the project.